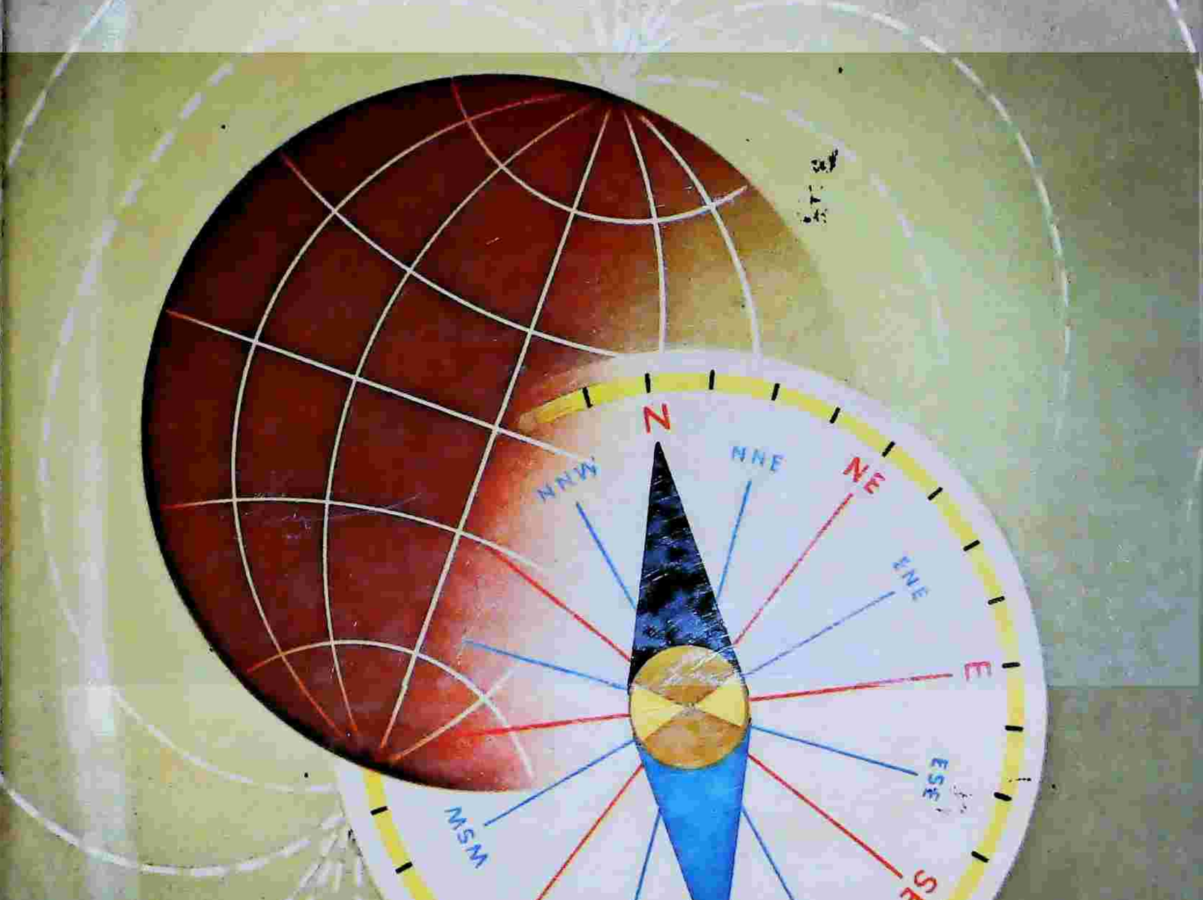
# MAGNETISM

## What it is and How Man Has Used It
## From Ancient Times To the Present



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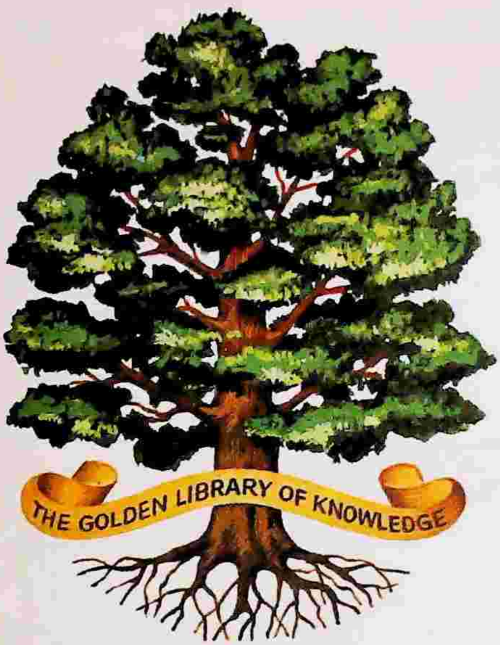
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# magnetism

## WHAT IT IS AND
## HOW MAN HAS USED IT
## FROM ANCIENT TIMES
## TO THE PRESENT

by RAYMOND HOLDEN

illustrated by WEIMER PURSELL

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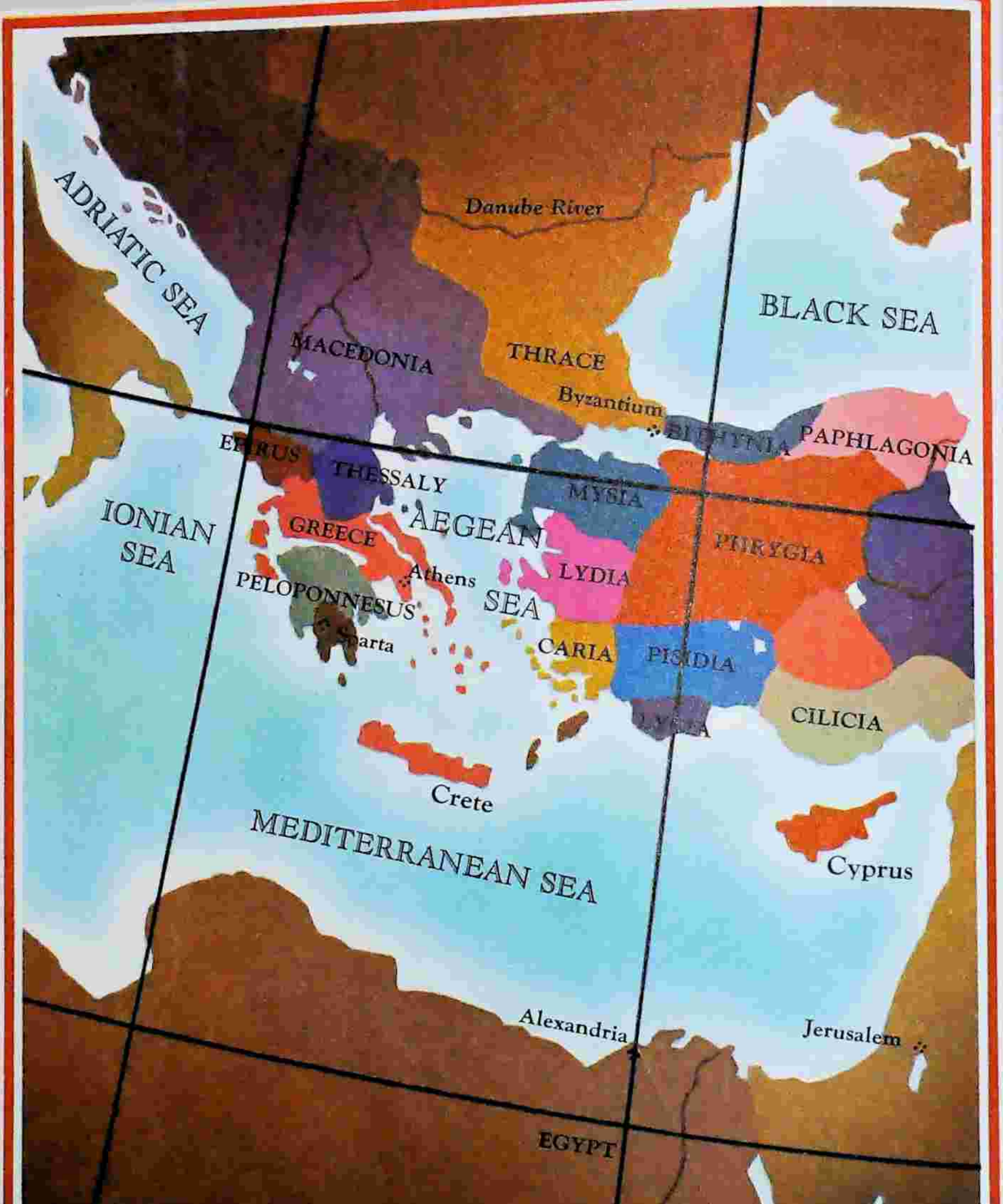


*This map of part of the ancient world shows Lydia where magnetite was first discovered.*

# What Is Magnetism?

Near the shores of the Aegean Sea in what is now Turkey, the ancient Greeks once made a surprising discovery. They found there a blackish metallic stone which was not like other stones. It was able, in some mysterious manner, to reach out and gather iron objects to it. Because this stone was found in Magnesia, in the ancient region of Lydia, it was called *magnes*. It was the iron ore which we call magnetite or lodestone, and it does reach out and gather objects to it.

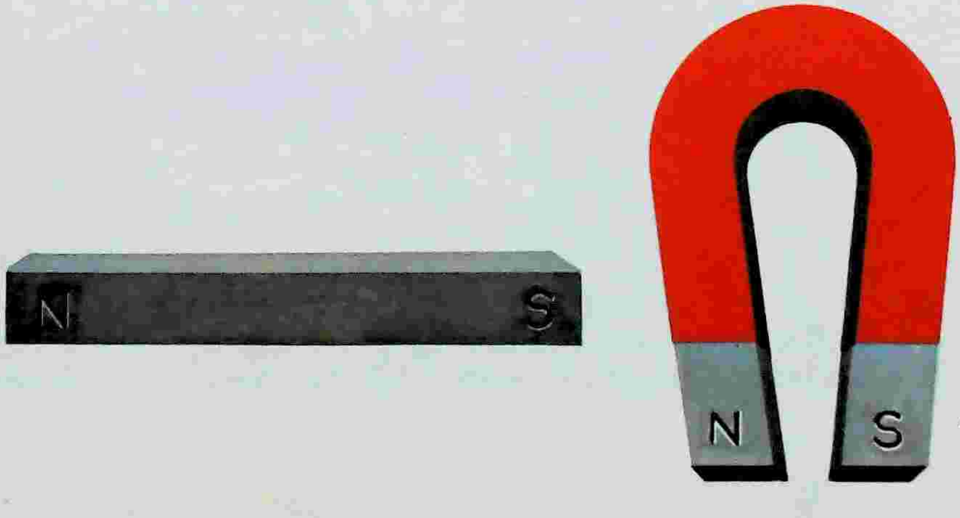
The ability of this stone to draw things to it or to push them away is called magnetism. Because magnetite is very highly magnetic and other metallic ores are not noticeably so, we are inclined to think that iron is the only magnetic substance. This is not really so. Nickel and cobalt are also very magnetic. Many materials, even gases, are also magnetic, but to a very small degree.

Some people think of magnetic stones as mere curios, and of artificial magnets as toys. Although magnets are fun to play with, they are far from being just toys and they appear in many forms.

Everyone is familiar with the commoner forms of artificial magnets—the simple bar magnet and the horseshoe magnet. The horseshoe magnet is simply a bar magnet bent into a U or horseshoe shape, so that its ends, or poles, lie close together and concentrate its strength.

A bar magnet, or any magnetized piece of iron or alloy (a blend of several metals), exhibits its magnetic force in actual curved lines, as shown in the illustration on the next page. These lines are densest at the two ends of the magnet where its strength is concen-

*A bar magnet (left) and horseshoe magnet (right) with north and south poles marked.*



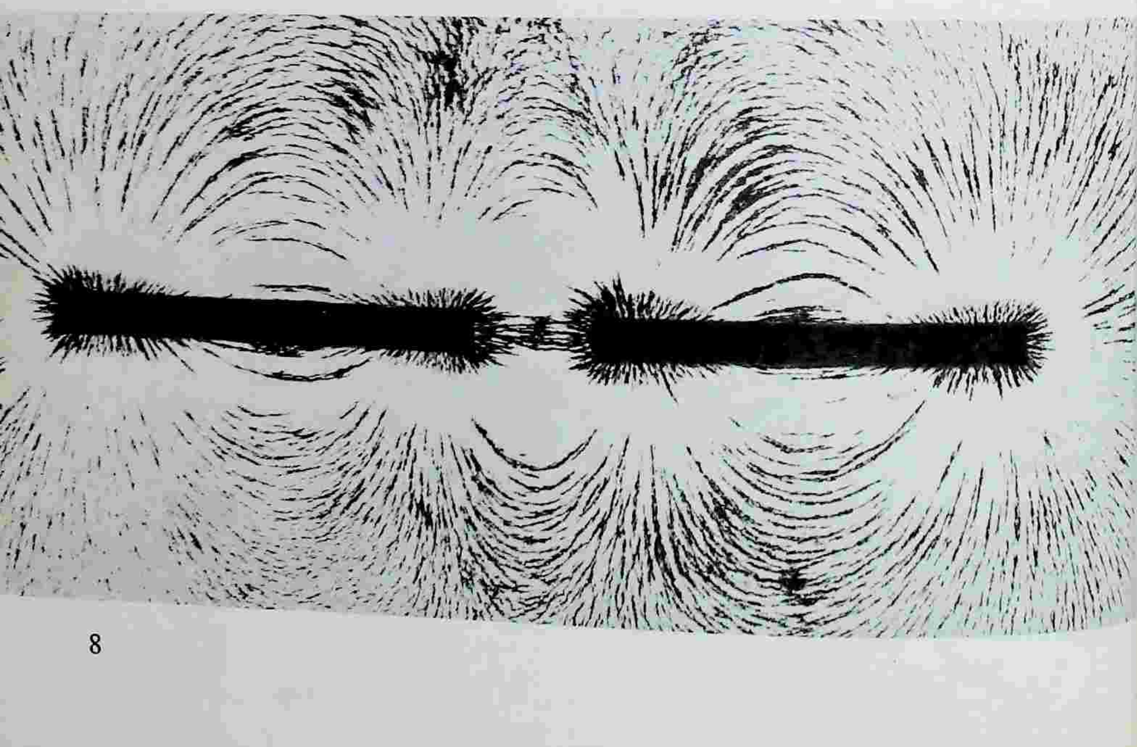
trated. The lines are not only flat, as the picture is; they surround the magnet like a cocoon of sticky air on all sides. Any substance which is attracted by the magnet will follow these lines in going toward it. The lines are called magnetic *lines of force*. They indicate the direction in which the magnetic force travels, rather than the strength of the force at any given point. The area covered by these lines is called the *magnetic field*.

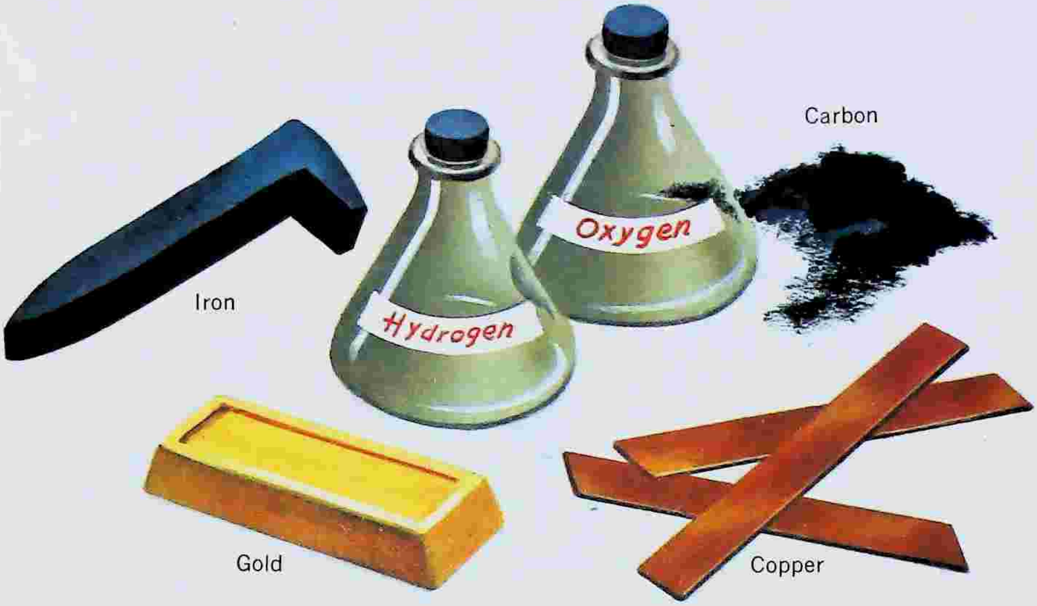
The quality of magnetism is mysterious. The Chinese knew it more than a thousand years ago, as did the Greeks and other ancient peoples who were familiar with metals. They thought, however, that it resulted from two spirits which lived in magnetic stone, one of them having an attractive force and the other a repellent force.

We have learned a great deal about magnetism in the last few years, but we are far from knowing everything about it. In order to understand what it means for a substance to be magnetic, we have to consider how substances are put together.

Few people today have not heard of atoms. We speak of the age in which we live as the Atomic Age, not because it is the age in which atoms were discovered but because it is the age in which men have learned enough about atoms to put the energy contained in them to practical use.

*The pattern of the lines of force of these bar magnets can be seen after iron filings are shaken on a sheet of glass that has been placed over the magnets. See page 48, also.*





*Elements such as gold, carbon, and copper are made up of like atoms. Magnetite is made up of two other elements—iron and oxygen.*

The smallest particle into which any element can be divided has for centuries been considered to be the atom. Two thousand years ago the Roman poet Lucretius gave a very clear description of what we would now call the atomic theory. Yet it remained for John Dalton, an English mathematician and chemist, to prove the theory shortly after the beginning of the nineteenth century.

An element is any substance that cannot be separated into different substances except by nuclear disintegration. There are about one hundred elements which, like iron, or gold, or carbon, are themselves and nothing else. An element, whether it is a solid like copper, or a gas like hydrogen or oxygen, is simply a gathering together of the atoms of the same kind which bear that element's name.

Atoms of one element often combine with atoms of another element to make a particle a bit larger than the atom. This is called a molecule, or "little mass." Thus the molecule of magnetite, the magnetic stone of ancient Lydia, is made up of three parts of iron and four parts of oxygen. Each iron atom is a magnet. The molecules may almost be thought of as little animals with heads and tails, the head of each one attracting the tail of the other and repelling its head. This attraction has the effect of lining up the molecules of magnetite like a school of fish all swimming in the same direction.

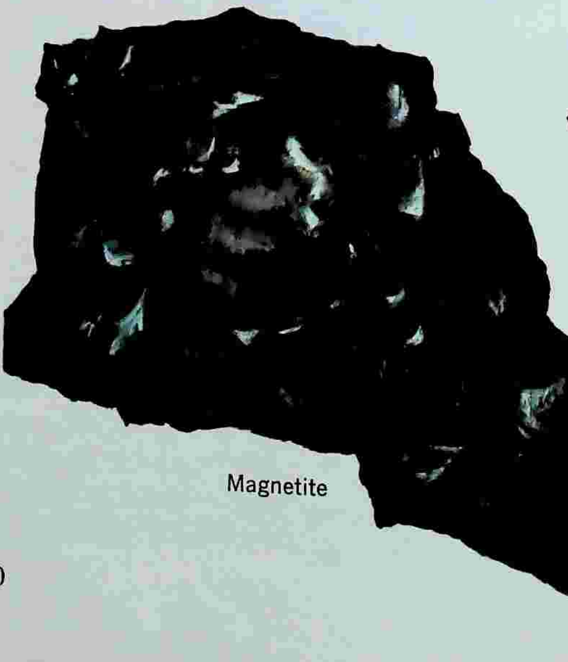
A lump of magnetite, however, is a body in itself, and has a head and tail of its own. The molecules are so packed together that although there are actually spaces between them, they appear to the eye to compose a solid lump of quite heavy metal. This lump of metal is a magnet and its head and tail are called poles. One is the positive pole and the other the negative pole.

Long before men knew that large magnets were collections of tiny magnets all of which behaved in the same way, they were fascinated by the force which a magnet exerted, and which suggested to them that there was some form of life or spirit in the stone. They discovered that this force could be given to a piece of iron by rubbing the iron with a magnetic stone.

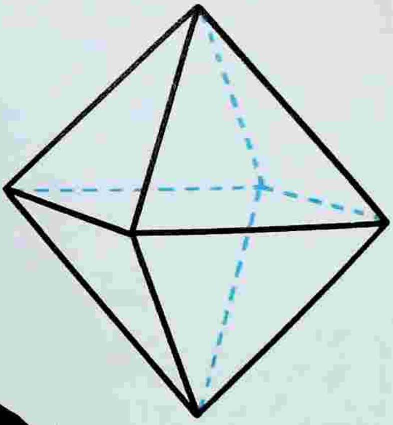
The Greeks were aware that lodestone could attract iron. Thales of Miletus, who lived from 640 B.C. to 546 B.C., thought that this power was due to a soul. In Plato's *Ion,* Socrates says that the stone "not only attracts iron rings, but also imparts to them a similar power of attracting other rings; and sometimes you may see a number of pieces of iron and rings suspended from one another so as to form quite a long chain."

The Roman Lucretius Carus writes in the first century B.C. "...iron can

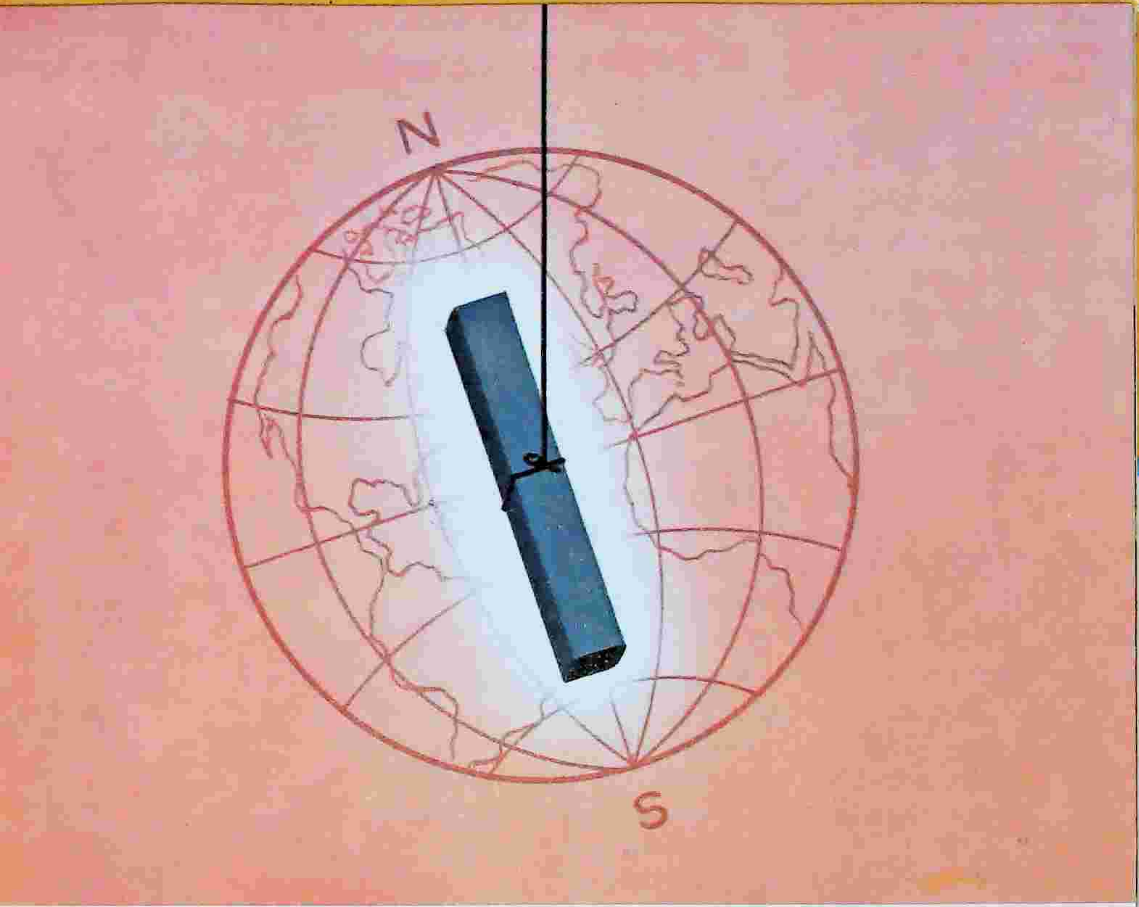
*Magnetite is a strongly magnetic black ore. It is hard and heavy for its size. Its crystals are usually in the form of octahedrons—that is they have eight faces.*



Magnetite



Magnetite Crystal



*A suspended, magnetized piece of iron will line itself up with the earth's magnetic field.*

be drawn by that stone which the Greeks call Magnet by its native name, because it has its origin in the hereditary bounds of the Magnetes." He also wrote, "Sometimes, too, iron draws back from this stone; for it is wont to flee from and follow it in turn."

As time went on, men learned, too, that a magnetized strip of iron, when suspended at its center, would point roughly to the north and south ends of the earth. They did not at first understand that the earth itself is a gigantic magnet and that the strip of magnetized iron was simply trying to line itself up with the earth's magnetic field.

The men of classical times did not know that a magnet had this ability. The first definite mention of polarity was in a dictionary in A.D. 121. In the eleventh century, a Chinese instrument maker, Shen Kua, mentioned the use of a magnetic needle for finding direction on land. After 1100, another Chinese man, Chu Yu, reported that the compass was used on the water.

The people who lived very long ago lacked an important part of the knowlvaries with the changes in the sound of the voice. The electric current which gives you light and power is usually produced by a dynamo or generator which would be powerless without magnets. The power delivered to these appliances, and to television sets, radios, and many others, is measured by a meter operated by a magnet.

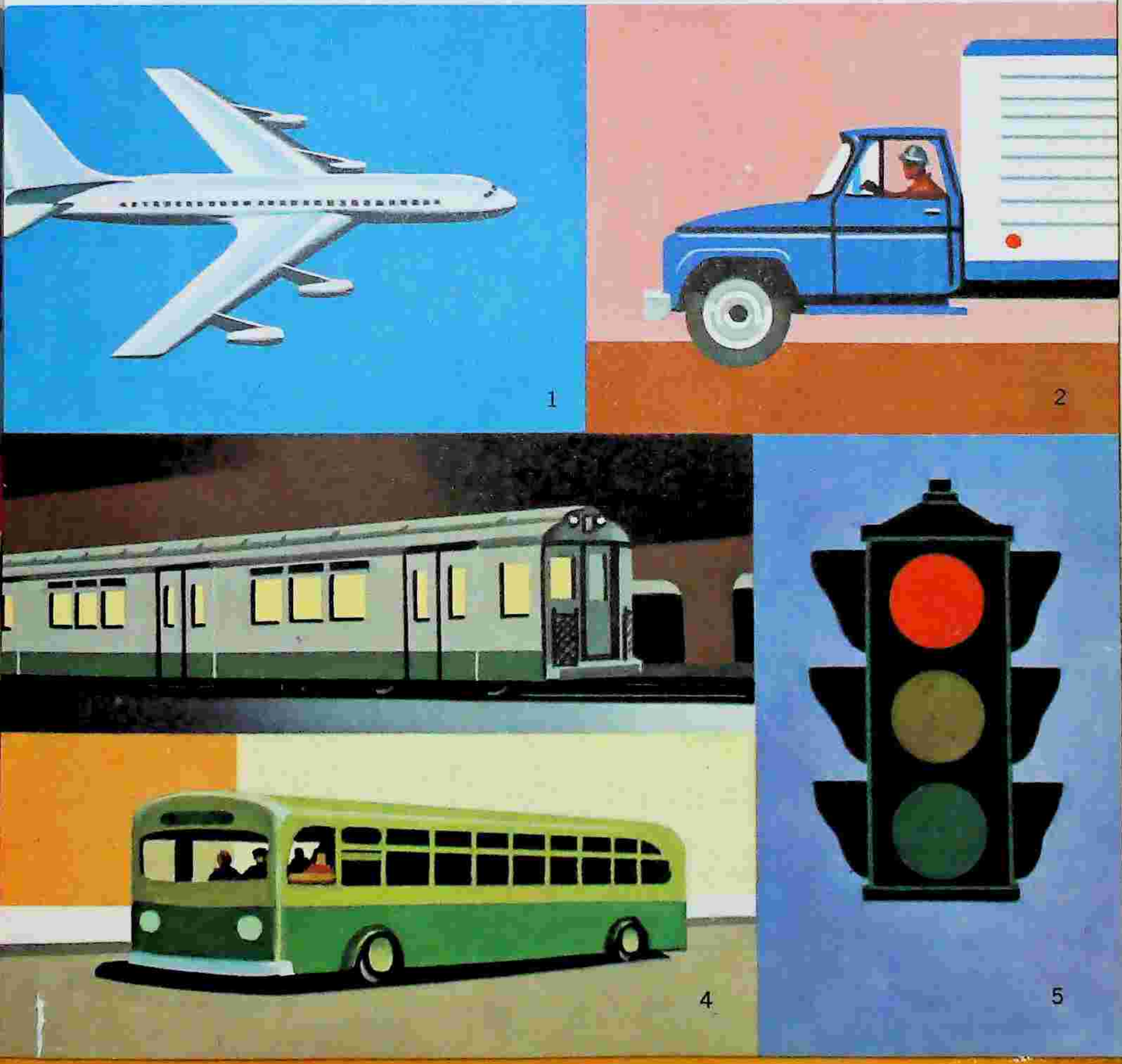
The refrigerator which preserves your food is, if it is electric, operated by a motor of which electromagnets are the heart. The phonograph which provides you with music very likely does so with the help of magnets. Dictating machines and musical tape recorders use a magnetic tape which is, strangely enough, made not of metal

*In the business world, magnetic tapes are used in dictating machines (1). In our homes, electromagnets are needed to operate oil burners (2), and refrigerators (3). Our pleasures are increased by the phonograph (4), which also utilizes a magnet.*

but of plastic coated with magnetic iron oxide powder. The cupboard doors in the kitchen may be held shut by magnetic catches. The oil burner which keeps you warm and the air conditioner which keeps you cool are operated by electromagnetic motors.

In the street, magnets are everywhere. That strange force which primitive men thought was a spirit is harnessed in taxicabs, buses, subway trains, trucks, and even in the switches which operate traffic lights. The electric motor is everywhere, and where there is a motor there is a magnet tugging at its shaft and forcing it to turn. A modern airplane uses more than one hundred electric motors.

*In the world of transportation, magnets are everywhere. (1) In the air, our powerful jets need magnets. On the ground, trucks and buses (2 and 4) run with the help of a magnet. Underground, subway trains (3) use magnets and traffic lights (5) use them, too.*



*William Gilbert, the English physician, said that the earth was a giant magnet.*

it do so, brings what it has located to the surface.

Yet it was only one hundred and forty years ago that a Danish scientist Hans Oersted startled himself and the world by discovering that magnetism and electricity were close relatives. There is no end to the possibilities which that simple discovery opened up for us.

It was not until the end of the sixteenth century that the subject of magnetism began to be studied with scientific care. In 1600, William Gilbert of Colchester, England, published a book about magnetism, *De Magnete*, which set men thinking about the mysterious force. Gilbert, who was the court physician to Queen Elizabeth, said that the earth was a magnet and that its surface magnetism probably came from magnetized material in its core. He wrote of magnetic declination and magnetic dip. He also wrote that magnetized iron lost its power of attraction when it was red hot, but regained it when it cooled.

Gilbert was convinced of the value of scientific methods and experiments. He said, "In the discovery of secrets and in the investigation of the hidden causes of things, clear proofs are afforded by trustworthy experiments rather than by probable guesses and opinions of ordinary professors and philosophers." However, he still believed that magnetism was something like a soul or spirit in magnetized metal.

There was something missing in the world of William Gilbert without which it was impossible for him to do more than point the way to men who were to come after him. That something was a knowledge of electricity.

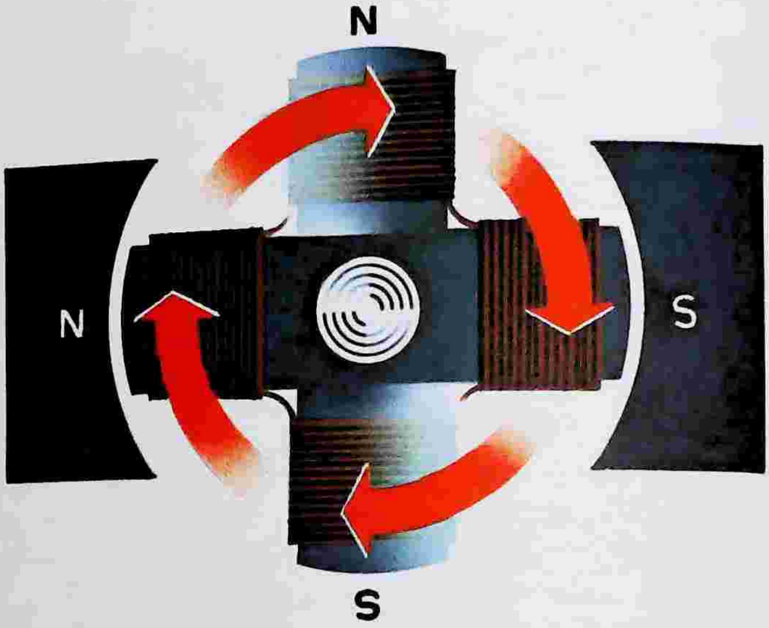
Seventy-five years after the publication of Gilbert's book on magnetism, Robert Boyle, a forty-eight-year-old Irish amateur scientist, published the world's first book on electricity. In this book he examined the curious fact that a piece of amber when rubbed with a silk handkerchief would behave, with certain light, non-metallic objects such as plant tissue or bits of paper, very much as a magnet behaves with bits of iron.

It was another seventy-five years before something happened which pointed out to men that the attraction which amber when rubbed had for bits of paper, was the same force which caused lightning to leap from cloud to earth and from earth to cloud. In 1752, Benjamin Franklin proved this by getting a spark from a thunder-cloud. Franklin's famous experiment with a kite, a string, a key, and a bolt of lightning made it possible for men to realize that lightning was the same as an electric spark.

At the same time, a Frenchman named d'Alibard reached the same conclusion as Franklin, namely, that lightning was simply an exaggerated form of the spark produced by rubbing amber with a silk handkerchief. But what did electricity have to do with magnetism?

Before another century had passed, electricity had become so familiar to scientists that it was the subject of countless experiments. In 1819, Hans

*Franklin tied a key to the spot where the kite's string joined a piece of silk ribbon. Carefully, he allowed the string and kite to get wet, but kept the silk ribbon and himself dry. Franklin brought his finger to the key and a spark jumped from it.*



*Generator: If pivoted bar is turned in magnetic field, current will be set up in coils.*
*Motor: If current is supplied to coils, pivoted bar will turn in magnetic field.*

It was in 1831 that one of the most remarkable figures in all science, Michael Faraday, succeeded in making a magnet–the magnet being the earth–produce electricity. He accomplished this by rotating a bar of soft iron wound with insulated wire, thus cutting the lines of force of the earth's magnetic field, an action which had the effect of setting up an electric current in the wire. Substituting an electromagnet, the dynamo, for the earth's rather unwieldy magnetic field, an invaluable application of magnetism was born.

In 1844, Samuel F. B. Morse sent the first message over an electric telegraph. Morse invented his telegraph with the help of scientific knowledge acquired by Joseph Henry, another American. Henry had discovered that an electromagnet could be worked from a great distance by wire. It remained for Morse to build an instrument which successfully used that knowledge to click out dots and dashes. He did this by suspending a bar on a pivot over an electromagnet. When, by means of a key or switch connected by wires to the electromagnet, the magnet was magnetized by an electric current, it drew the bar down and made a click. When the switch was opened, the magnet lost its magnetism and the bar was pulled away by a spring making another click. A short click, or dot, was made by pressing the key quickly and then releasing it. A long click, or dash, was made by holding the key down.

Morse once stated, "The essence of my invention being the use of the motive power of the electric or galvanic current which I call 'electromagnetism' however developed, for marking or printing intelligible characters, signs, or letters at any distances, being a new application of that power of which I claim to be the first inventor or discoverer."

This particular claim of Morse's was not supported by the Supreme Court of the United States. It ruled that a law of nature could not be patented by any man. But Morse's telegraph laid the groundwork for the modern telegraphy system we have today.

*Samuel F. B. Morse (1791-1872), was a painter as well as an inventor. In fact, in 1832 he was a professor of painting and sculpture at the University of the City of New York. In 1837, he gave up the field of art and devoted himself entirely to electrical invention. Besides being known for the invention of the telegraph, he also devised the famous Morse Code.*

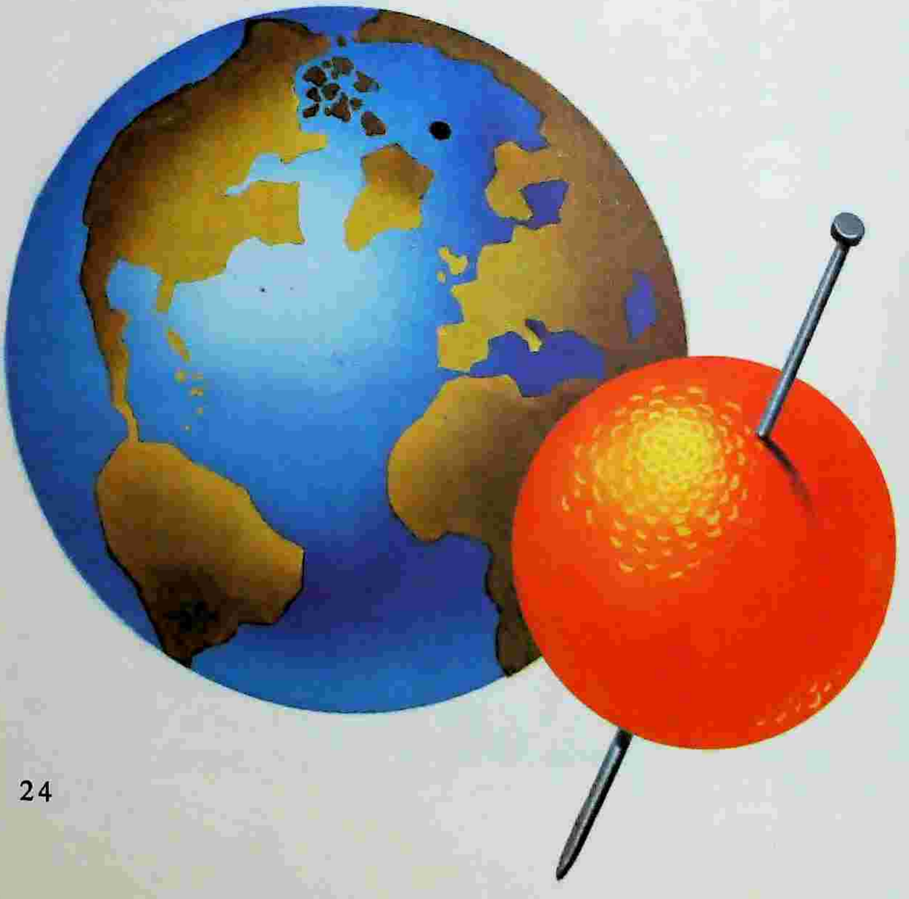
# The Earth Is A Magnet

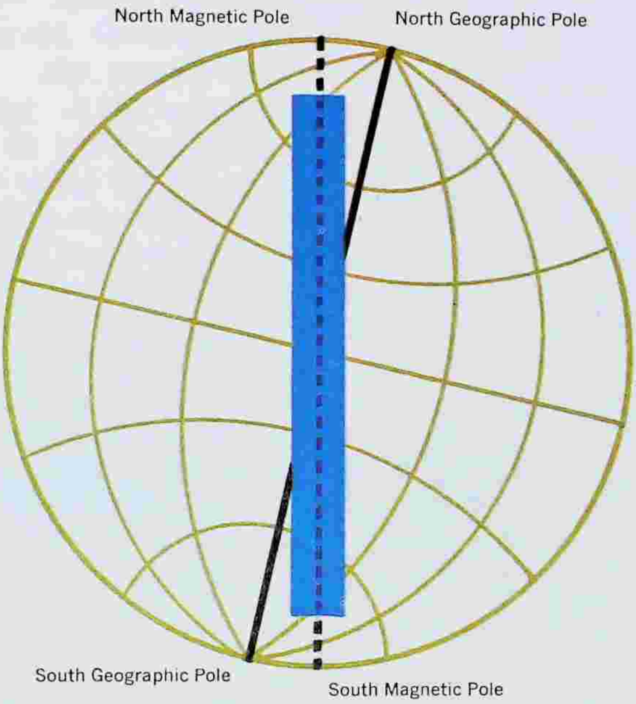
Although our planet is made up of all the chemical elements in different combinations and proportions, and although the crust of the earth is mostly granite, the earth behaves magnetically very much as if it were a ball of solid metal.

Being a sphere which is constantly spinning like a top, it has what is called an axis. The earth's axis is an imaginary line drawn through the center of the globe, like a knitting needle pushed through an orange. If you twist the needle the orange will rotate. We may imagine that the line drawn through the center of the earth, the knitting needle about which the planet spins, comes through the earth's rind at two places, one on top of the globe and one on the bottom. The top place is the North Pole and the bottom one is the South Pole.

We know that a magnet has poles

*The earth's axis runs from the North Geographic Pole to the South Geographic Pole. The knitting needle in the orange illustrates the approximate position.*





*The dotted line running through the bar magnet lines up with the North Magnetic Pole and the South Magnetic Pole. These are not the same as the North and South Geographic Poles.*

where its magnetic forces are concentrated, but in the earth the magnetic poles are different from the geographical poles. Actually, the earth is like our orange into which someone has pushed a bar magnet without trying to push it along the exact axis about which the sphere spins. This magnet lies in the orange in a position which makes an angle with the axis connecting the geographical North Pole and the geographical South Pole. One pole of the magnet, though it does not reach the surface of the orange, exerts a force upon the surface which is concentrated in a spot called the North Magnetic Pole. This second North Pole is, in our planet, quite a distance from the geographical North Pole, which was discovered by Admiral Peary in 1909.

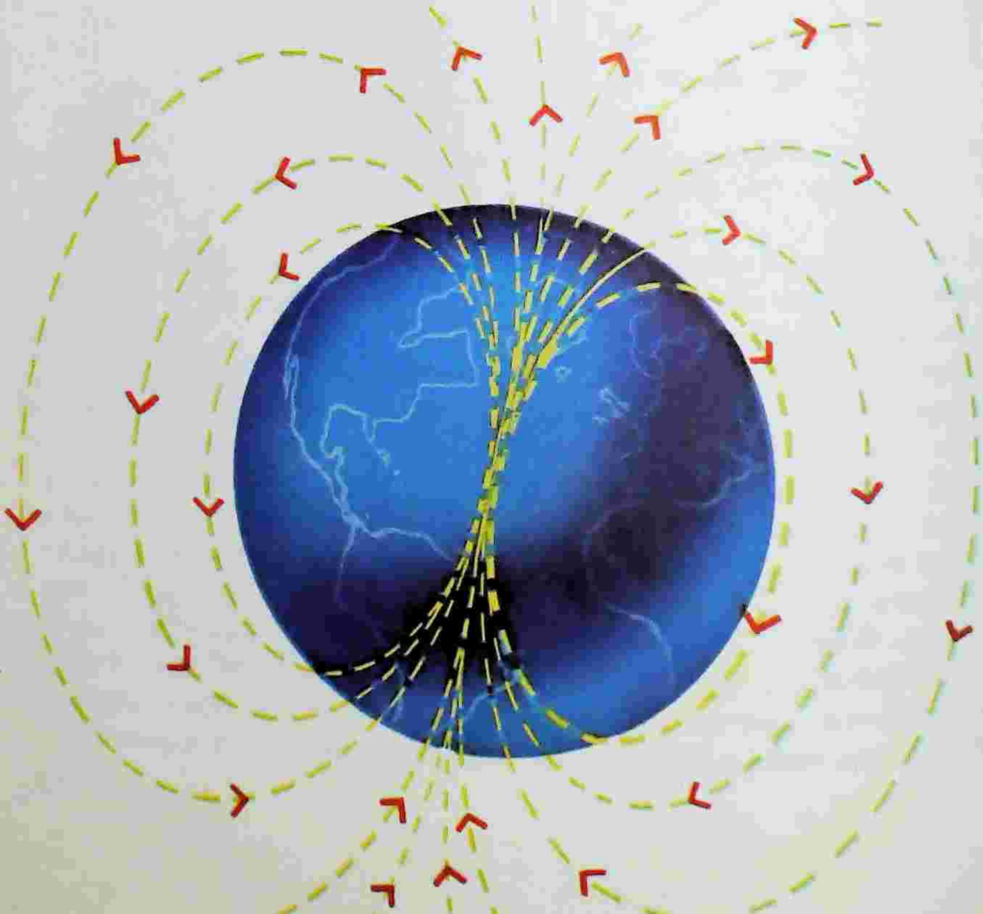
The same thing is true in the south. The effect of the magnet in the earth makes itself felt at a South Magnetic Pole which is as far from the Pole which Roald Amundsen reached in 1911 as the North Magnetic Pole is from the North Pole. The existence of these extra poles is very important.

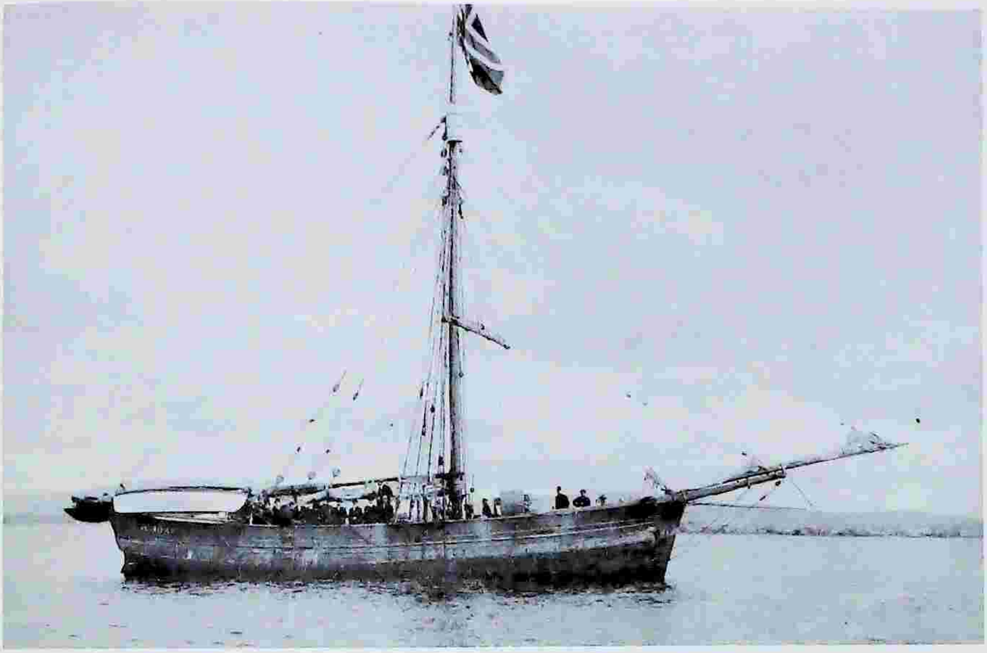
How does it happen that the earth, which is not entirely metallic, and which we know has a hot, liquid core, can behave as if it were a solid lump of magnetized metal? In trying to answer this question we have to turn to what William Gilbert could not have known when he tried to explain the earth's magnetism three hundred and sixty years ago. This is the behavior of electric currents. We now know that electric currents can produce magnetism even in gases or fluids.

It is necessary to suppose that there are electric currents in the molten metal of the earth's core. We do not know exactly what set them going, but like all electric currents they are surrounded by a magnetic field.

The spinning of the earth causes the surface of the globe to act as if it were the outer part of a dynamo, changing the mechanical motion of its spinning into electric currents which reinforce the currents in the earth's core. Thus the earth stays alive as a magnet, with the lines of force over its surface and gathered together at its magnetic poles. Just as all magnets have lines of force densest at their poles.

*As the earth spins, electric currents are formed which reinforce those in the earth's core. Therefore, the earth remains a magnet with its lines of force.*





*After three years in the Arctic, Amundsen arrived at Nome, Alaska, in August, 1906.*

# The Search for the Meaning of Magnetism

In the nineteenth century, men learned more about magnetism and what it could be made to do for them, but they still had little or no idea of the real relationship between magnetism and electricity. They could not be expected to, without knowing more about the earth as a magnet. So it was that scientists began to gather together what facts they could about the magnet under their feet and its enormous and complicated field of force.

By the beginning of the twentieth century, men knew roughly where the North and South Magnetic Poles must be. Mathematics could tell them where the true North Pole was. The compass needle pointed somewhere else. It began to seem advisable to study the effect of magnetism in parts of the earth where it had not yet been observed. The region about the North Magnetic Pole was one of these.

The great Norwegian explorer Roald Amundsen set out early in the summer of 1903 in a small motor sloop named *Gjoa* to try to find a way by water from the Atlantic to the Pacific, and incidentally to make a series of observations near the position then occupied by the North Magnetic Pole. Although the Magnetic Poles move and change position, in September of that year he located the pole on the west side of Boothia Peninsula, some two hundred miles south of the actual North Pole.

Amundsen built a camp and spent the winter about ninety miles from the Magnetic Pole and took readings of his instruments regularly. This was the beginning of the modern magnetic observation which reached its peak during the International Geophysical Year of 1957-1958.

During the past fifty years, magnetic observations have been taken at thousands of points in every part of the earth. In the early years of this century, the Carnegie Institution fitted out a nonmagnetic ship made of wood held together with fastenings of bronze and copper. Only a very small quantity of iron was used. This beautiful sailing ship carried instruments for measuring the direction and intensity of the lines of force in the earth's magnetic field. The *Carnegie*, as she was called, sailed the seas for many years collecting records of the earth's magnetic force. She was finally destroyed by fire and abandoned in the South Seas. Since then her work has been taken up by others.

Observation parties have traveled through the jungles of Africa and South America doing on the land what the

*The full-rigged ship Carnegie sets sail on her mission to measure the magnetic field of the earth. The graceful wooden ship, with her canvas sails, carried little metal, other than the fittings necessary to hold her together, so that the magnetic instrument readings would be as accurate as possible.*

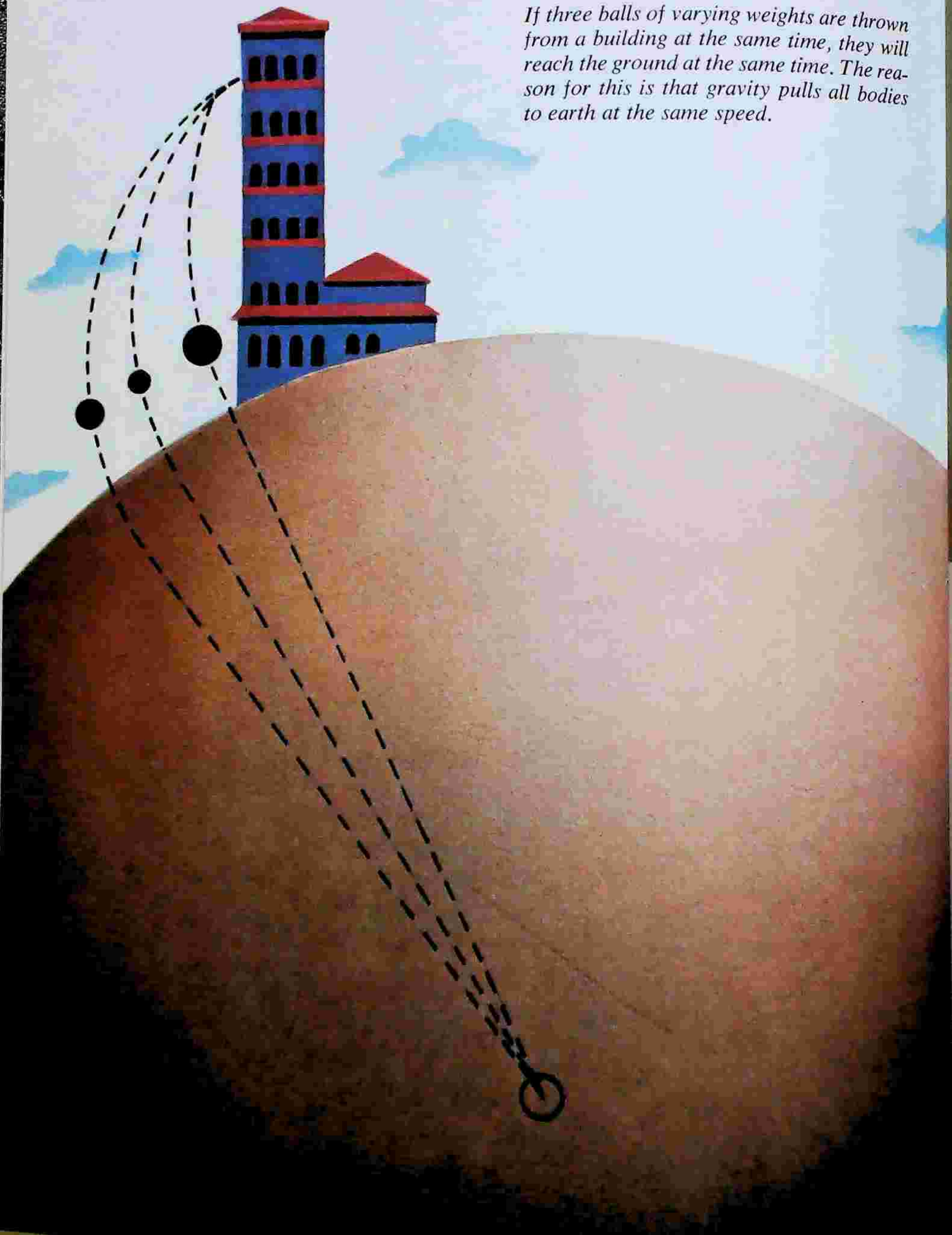
*The building seen in the above photograph is Rawin Dome. It is a part of the International Geophysical Year installations maintained by the United States at Little America Station, Antarctica.*

sailing ship *Carnegie* did on the sea during her years of scientific work.

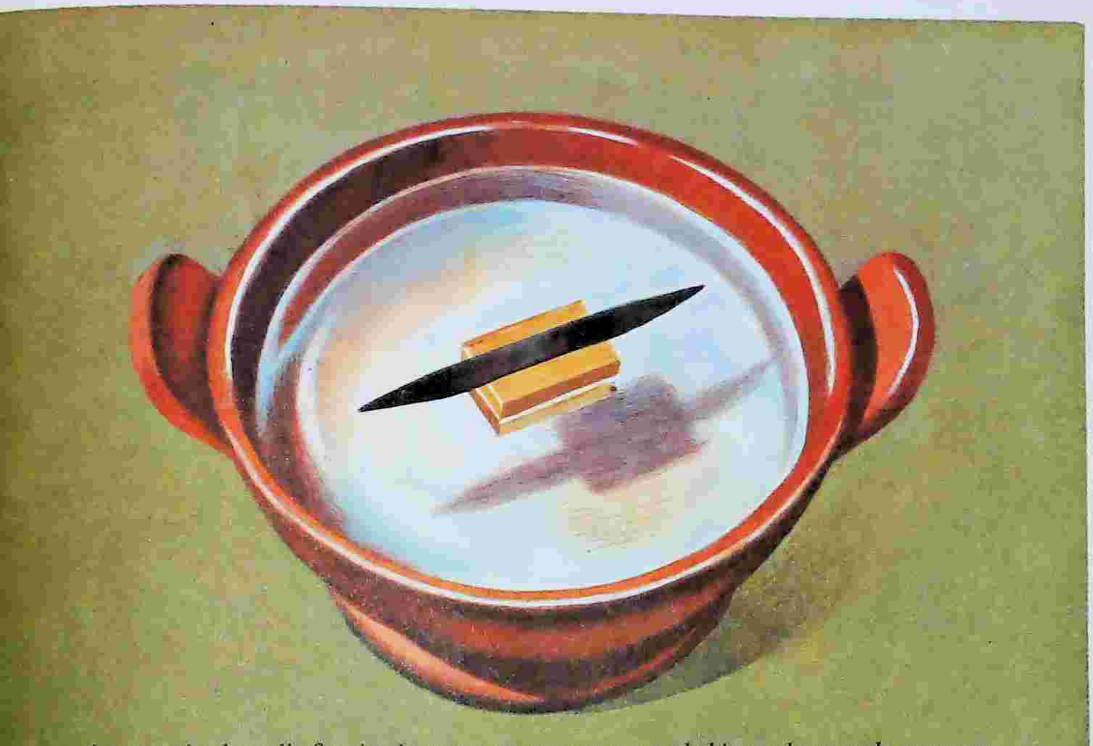
Today, as a result of all this pioneer work, we have an almost perfect picture of the magnetic force of the greatest magnet known to us. Yet until very recently we have had only a vague idea of what gives the earth its magnetism, which in turn causes the magnetic force the Greeks found in the Lydian stones.

In 1957-1958, the nations of the world joined together in a scientific undertaking of tremendous importance called the International Geophysical Year. It was during this year that observation stations were maintained in all parts of the earth, particularly in the Antarctic Continent. Much of the work of these stations was devoted to the study of magnetism.

The results of all of these observations have brought about a great change in our thinking about the magnetism of the earth.



*If three balls of varying weights are thrown from a building at the same time, they will reach the ground at the same time. The reason for this is that gravity pulls all bodies to earth at the same speed.*



*A magnetized needle floating in water on a straw or wood chip made an early compass.*

# Gravity and Magnetism

Anyone at all observant might be forgiven for saying, "Why, of course the earth is a magnet! If I hold up this lump of iron and let go of it, the earth will reach out and pull it down." True. But the earth will also pull down a block of wood or a feather, while a true magnet has no effect upon a block of wood or a feather. The force which makes things fall to earth is not magnetism, although in many ways it resembles the pull of a magnet. It is what we call gravity, a force which is the result of the earth's mass and the object's mass, and not of the magnetization of its molecules. If you climb a tower and drop stones from it, they will fall toward the exact center of the earth no matter how far out you may throw them. The force of magnetism in the earth is quite different from the force of gravity.

We have seen that men knew long ago that a strip of magnetized iron, suspended at its center and free to turn, would point roughly to the north and south ends of the earth's axis. So long ago that no one knows exactly when it was, men used their knowledge of this fact to make an instrument which has come to be called the compass, and which could show them the direction in which they traveled.

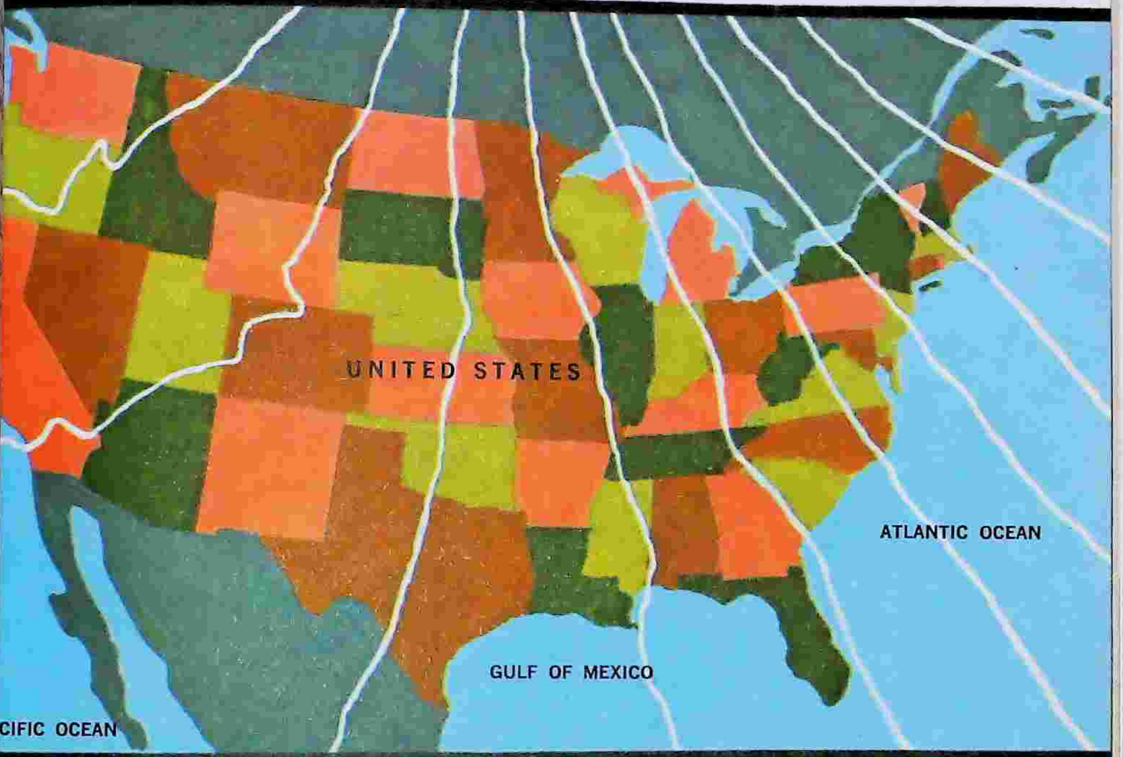
The compass in its earliest form was probably a magnetized needle resting on a stick or straw which floated in a dish of water. It could not have been accurate in anything but a very general way. Indeed, it was not until the nineteenth century that the accurate modern compass was developed.

Some say that the Chinese were the first to use the compass many centuries ago. Now it is also thought that the compass might have first been used in navigation in the Mediterranean, possibly by the Arabs. Perhaps like some other great inventions, it appeared independently in several places.

The earth's magnetic force affects the compass needle in several ways. The point marked north on the needle does not, as many people believe, always point to the North Magnetic Pole. It is true that if you traveled north according to the pointing of the compass, you would eventually reach the region in which the North Magnetic Pole is located, but you would have traveled a twisting course.

This is because the effect of the force of magnetism within the earth is not exerted equally in all parts of the earth's surface. If we should draw lines from the North Magnetic Pole to the South, lines which would always be parallel to the compass needle, they would look like the wanderings of a snail, as is shown in the illustration. They would be a series of almost parallel wavy lines. At any point on any one of these lines

*A modern pocket compass like this one has sixteen main points on it. It is a great help to a person who gets lost. All he needs to know, if he has a compass, is the direction in which he should be going.*



*The variation of the magnetic compass from the true north is magnetic declination. This map shows the distribution of magnetic declination in the United States in 1955.*

the compass needle would point north and south directly along the line, no matter how far the line deviated at that point from true north and south.

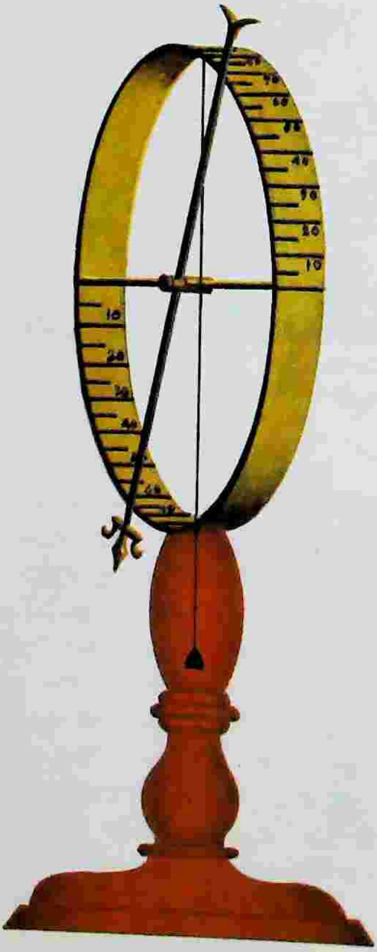
As the lines all end up at the magnetic poles, it is obvious that to follow them one way or the other would get you to the North or South Magnetic Pole in the course of time, though frequently you would have been traveling neither true north nor true south.

If you again imagine the earth as an orange with a bar magnet fastened inside at which you could throw a cupful of iron filings, those iron filings would cling to the orange in lines very much like those in the picture of the bar magnet and its lines of force. The compass needle is simply an iron filing constantly trying to line itself up with the earth's lines of magnetic force.

It can easily be seen, therefore, that magnetism is quite unlike that other great force, gravity, which draws things directly toward the center of the earth's mass.

# The Use of the Magnetic Compass

Many people – the Chinese, Arabs, Etruscans, Italians – have been called the inventors of the compass. The first European mention of the compass was made by Alexander Neckam in the twelfth century. He then wrote of a needle used on board ship that showed sailors their course.



*A sixteenth century dipping needle. The needle followed the direction of the earth's lines of force, and measured magnetic dip. The stand was of wood. The rest was brass, except for the iron shaft of the indicator, and the string with lead tip.*

When the compass was first used in navigation, little or nothing was known about the peculiarities of the earth's lines of magnetic force. Eventually it was discovered, first, that the compass needle in most places on earth never pointed to true north. Next, it was realized that the angle between its direction and true north was different not only at every point on the earth's surface, but even at the same point was not the same from year to year or from hour to hour.

Instead of causing man to throw away the compass because it seemed inaccurate and deceptive, this baffling fact made scientists figure out ways of foretelling the changes in compass reading. In this they have, indeed, had remarkable success.

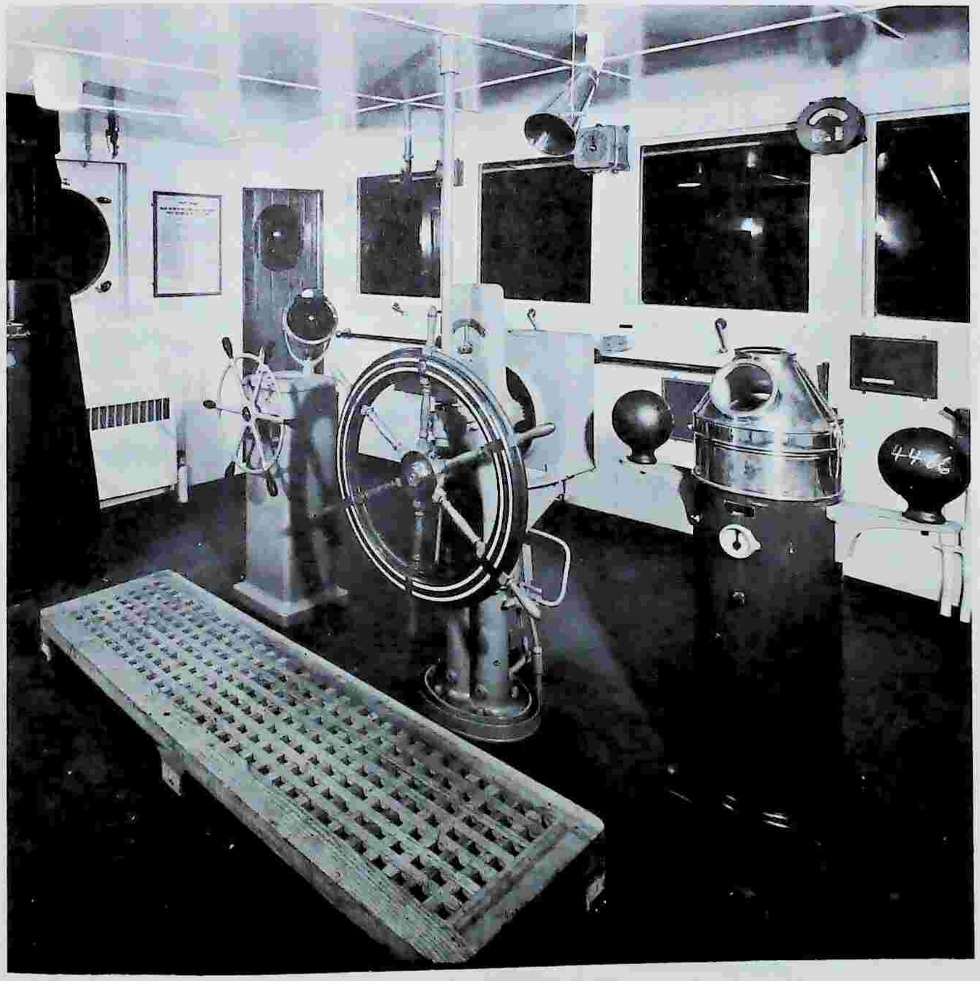
There are now tables which tell navigators just what is the variation of the compass. Variation is the number of degrees between compass north and true north at any location on the earth's surface in any year and at any time of day or night.

There is another variation of the compass needle which is also of great significance. This other variation is an up and down variation called *dip*.

If the compass needle were fixed so that it could swing up and down instead of sideways, it would dip at a different angle in all parts of the earth. Theoretically it would have its north-pointing pole headed straight down at the South Magnetic Pole. At the magnetic equator, equally distant from the North and South Magnetic Poles, it would not dip at all.

What we know about the compass needle enables scientists to draw a kind of map of the earth's lines of magnetic force.

*In the wheel house of this ship, the magnetic compass stands to the right of the steering wheel. To the left is a repeater from the master gyrocompass.*



# Sun Spots and Magnetism

It is known that the earth's magnetic field—the area in which the force of the earth as a magnet is felt—is often violently disturbed. Roald Amundsen, the Norwegian explorer who reached the South Pole in 1911, saw evidences of this in 1903 and 1904, on the recording instruments which he had set up in Boothia, northern Canada, to keep track of the direction and intensity of the lines of magnetic force.

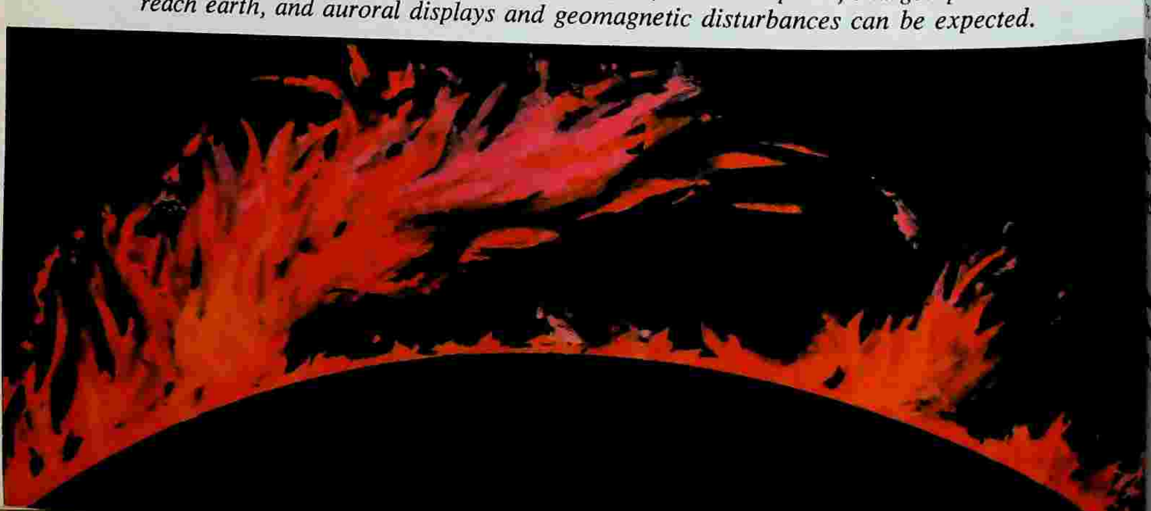
Sometimes the graph showing a record of the direction of the compass needle would be a steady line about the recording cylinder which turned once every twenty-four hours. Sometimes, however, the needle quavered and jumped so that for long stretches the line on the paper looked like a range of sharp-peaked mountains.

It has also been known that at certain times portions of the sun are obscured by dark spots. The appearance of these spots seemed always to be associated with solar storms or a great disturbance of the earth's magnetic field. There are other changes in the sun which are associated with its spots, and they have a disturbing effect on our planet. These are usually spoken of as solar flares. They are enormous eruptions of flame, leaping thousands even hundreds of thousands of miles into space.

We now understand that these violent outbursts of the sun's energy are accompanied by unbelievable discharges of electricity. Streams of electrically charged particles are shot in all directions, one direction being toward the earth. On the right sort of radio detector they can actually be heard as if they were signals.

During periods of intense electrical discharge from the sun, strange things happen to the earth's magnetic field. Not only do compasses act up, but radio and

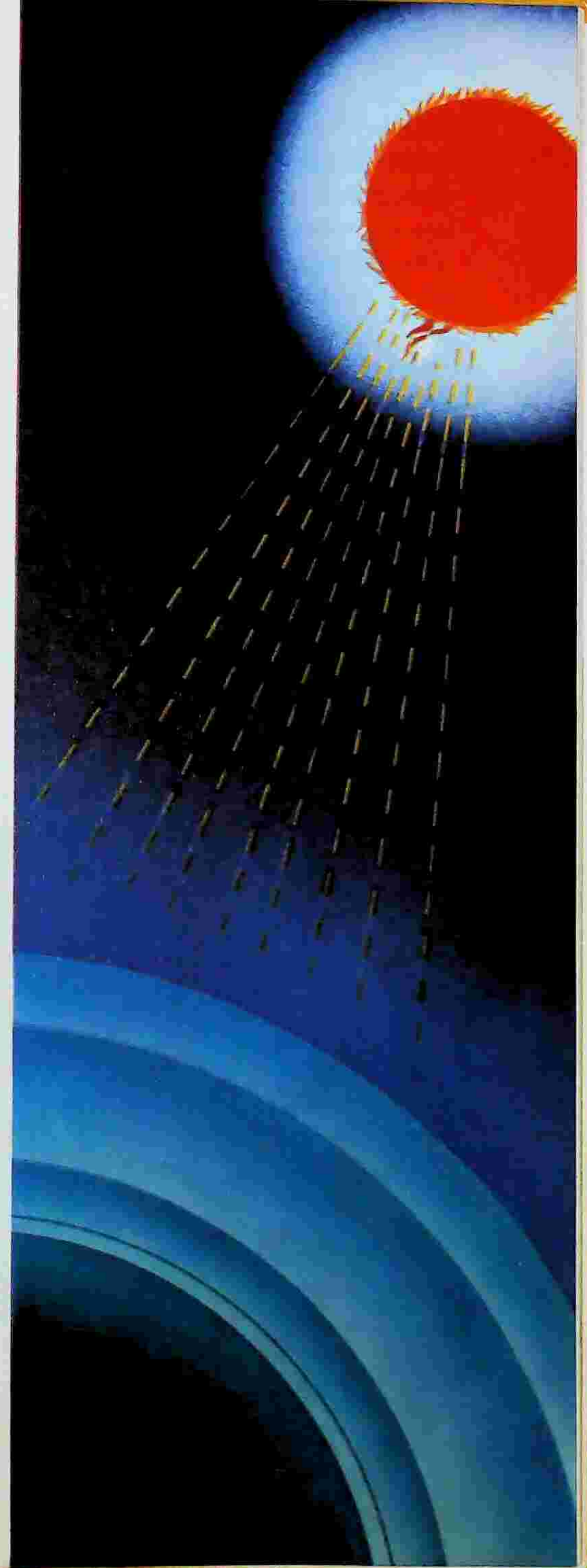
*Solar flares achieve maximum intensity in a few minutes, but they sometimes can be seen for an hour or more. Within two days after the eruption, charged particles reach earth, and auroral displays and geomagnetic disturbances can be expected.*



television communication is interfered with and often stopped entirely. Transmission lines for electrical power, whether above or below ground, act as if they were overloaded and set off devices intended to protect them from burning out. The result of this is that lights go out and power is shut off in houses and factories. The electromagnetic storm, which has neither wind, snow, nor rain, nevertheless, has a devastating effect because the sun is a generator of electricity and the earth is a gigantic magnet.

Radio, telephone, telegraph, and cable companies are, of course, very much interested in these magnetic storms. They must learn when their services are likely to be knocked out. One corporation maintains a network of observation stations and gives out regular bulletins predicting magnetic weather conditions, just as the Weather Bureau predicts what the weather of the atmosphere will be.

The last great magnetic storm was in February, 1958. It will probably be 1969 or 1970 before anything like it can be expected to happen again. It has been discovered that sun spots and sun flares appear most violently at regular intervals of about eleven years. No one knows why. Before the storm of February, 1958, began, an observer in New



*Streams of electrically charged particles penetrate the earth's atmosphere and affect life on this planet.*

Mexico was watching the sun through a special instrument which covers the blazing disk and allows the observer to see only what is taking place on its rim. This observer suddenly saw a series of bright streaks above the obscured face of the sun, which made it look as if a series of lightning strokes had touched off an atomic explosion.

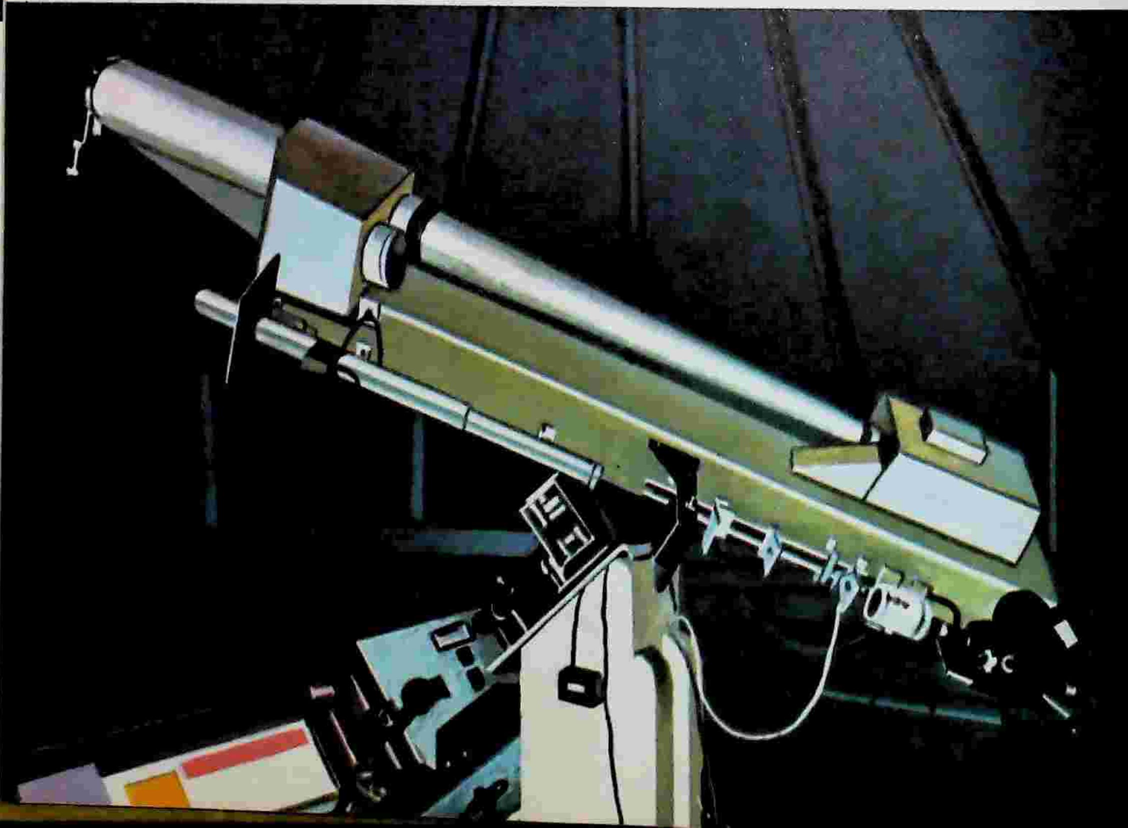
It was, indeed, an atomic explosion, far greater than any which man could produce. The observer had been looking for something like this as it was about time for a solar eruption, but he had not expected anything quite so violent. He knew what was going to happen. A vast cloud, thousands of times larger than the earth, of electrified particles was about to make its way toward our planet and completely engulf it.

The observer immediately notified the International Geophysical Year's Data Center in Colorado, to which all evidences of unusual activity in the sun were to be reported. The Center sent out bulletins notifying the rest of the world of the explosion.

The cloud of electrified particles from such a sunburst travels at nearly one thousand miles a second. It was therefore clear that within a day our planet was going to suffer an invisible bombardment which would throw every form of communication out of kilter.

It did. Europe was cut off from North America. Newspapers could get no

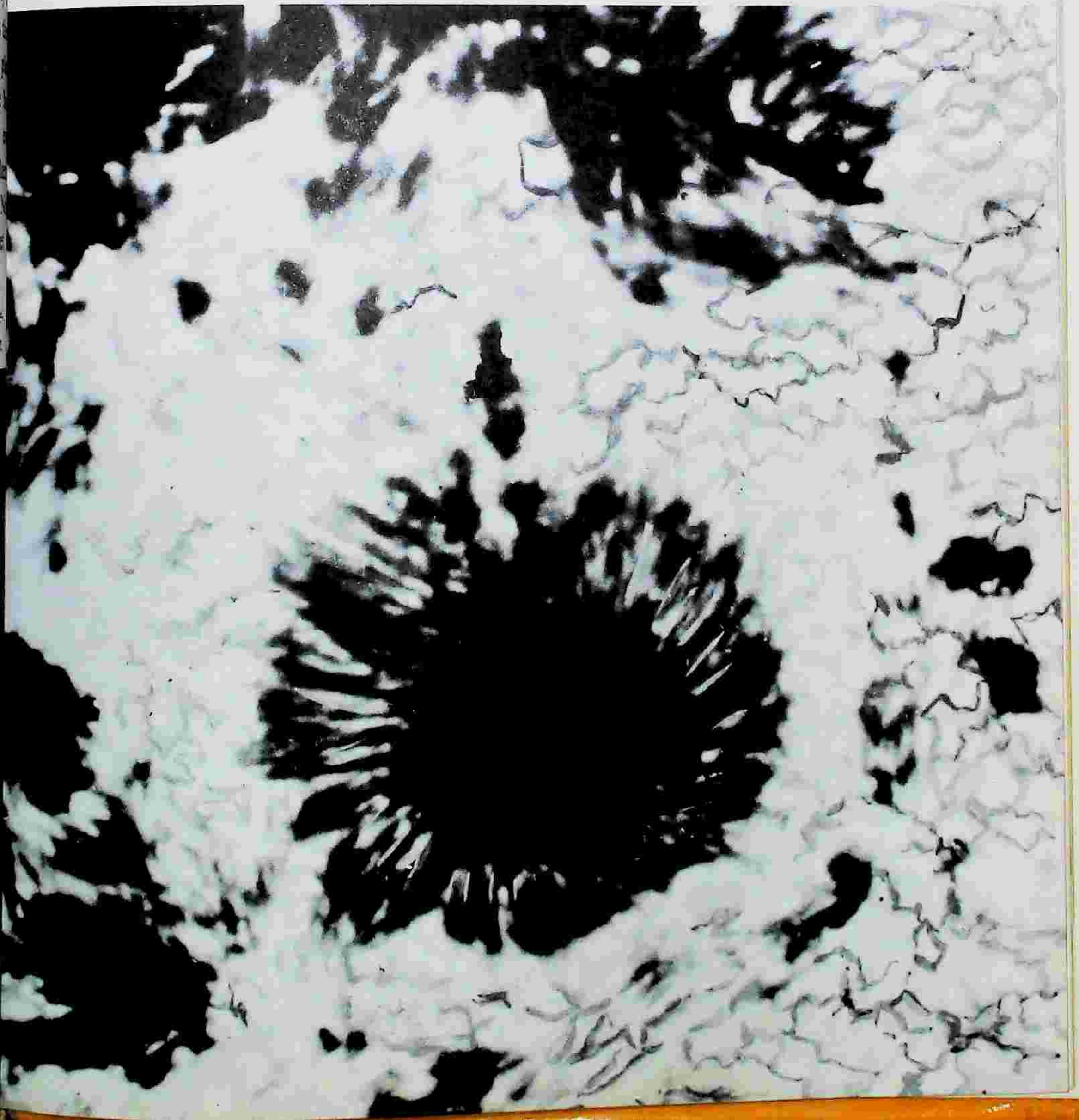
*A coronagraph and flare camera. The coronagraph is a special kind of telescope that allows an observer to see the corona, or outer atmosphere of the sun.*



news. Airplanes could get no helping signals from the ground. Compasses swung out of line. If it had not been past midnight when the magnetic storm was at its peak, the results might have been more serious.

By early morning, the great cloud of electric power had passed on, leaving our planet slowly returning to normal functioning. Our sky, north and south, was hung with a strange radiance, sometimes with an arc of glowing red and blue fire, and sometimes with a waving ribbon of blue-green – marking, perhaps, the outer limits of the earth's disturbed magnetic field.

*On this photograph of the face of the sun, the sun spots appear as black marks.*



# The Aurora

The appearance of colored lights in the night sky is, as we all know, nothing new. In ancient times it was thought to be a heavenly indication of important coming events—the death of kings, pestilence, warfare, or rebellion. It is only in comparatively recent years that it has been associated with the earth's magnetic field.

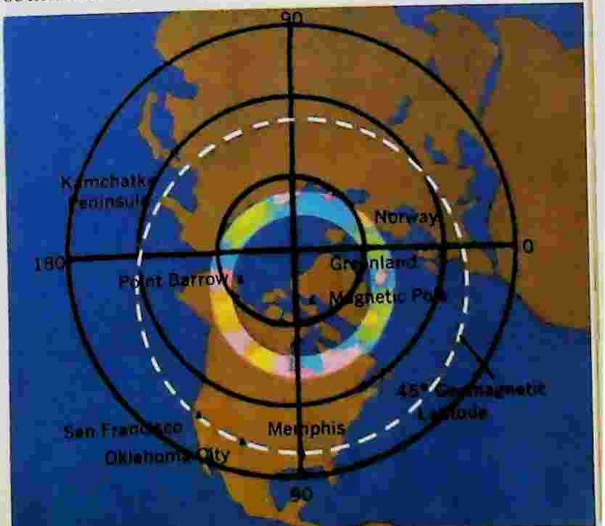
The *aurora,* whose name comes from the Latin word for dawn, is an illumination of a part of the night sky which does not come from sun, stars, or moon. It is commonest in a circle about the most northerly and southerly parts of the earth. During periods of sun flares and magnetic storms, however, it is often seen much nearer the equator.

The aurora takes many forms and all of them, however terrifying they may have been to the ancients, are beautiful. This spectacle may be merely a glow in the sky. It may be an arc, bright as a rainbow. It may be a hanging array of shining, waving, shimmering points of light. It may be a band of bright color which seems to weave and waver in the night wind. It may be a circle directly overhead with streamers descending from it to the horizon, like the garlands looped on a maypole. Whatever form it takes, it is thrilling and spectacular and makes man more aware of the varied forces in the earth and sky.

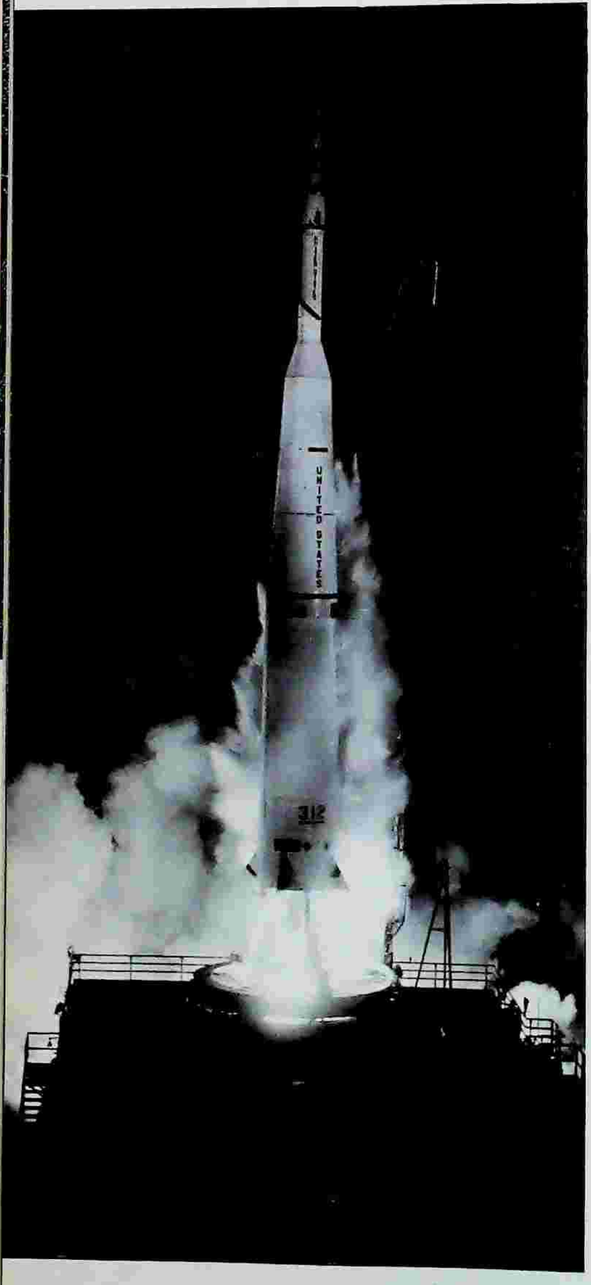
No one yet knows all about the nature of the aurora, but there seems little doubt that it has some connection with that layer of space beyond our atmosphere from seventy to five or six hundred miles up, which is filled with incredibly small air particles carrying electrical charges. These particles are known as ions and the layer of space in which they exist is called the ionosphere. It is known that when this layer—it is really a series of layers—of electrified air is violently disturbed by electric currents from the sun or by cosmic rays of unknown origin, auroral display becomes greater and spreads over a far wider area of the heavens than it ordinarily occupies. The movement of the aurora is caused by the shifting earth's magnetic field during a solar storm.

◄ *An antenna is used to study radio noise and wave reflections from this "curtain" aurora.*

*The colored circle shows where auroras are seen most often; the dotted circle is the southern boundary of auroral displays.*



# Magnetic News From Outer Space



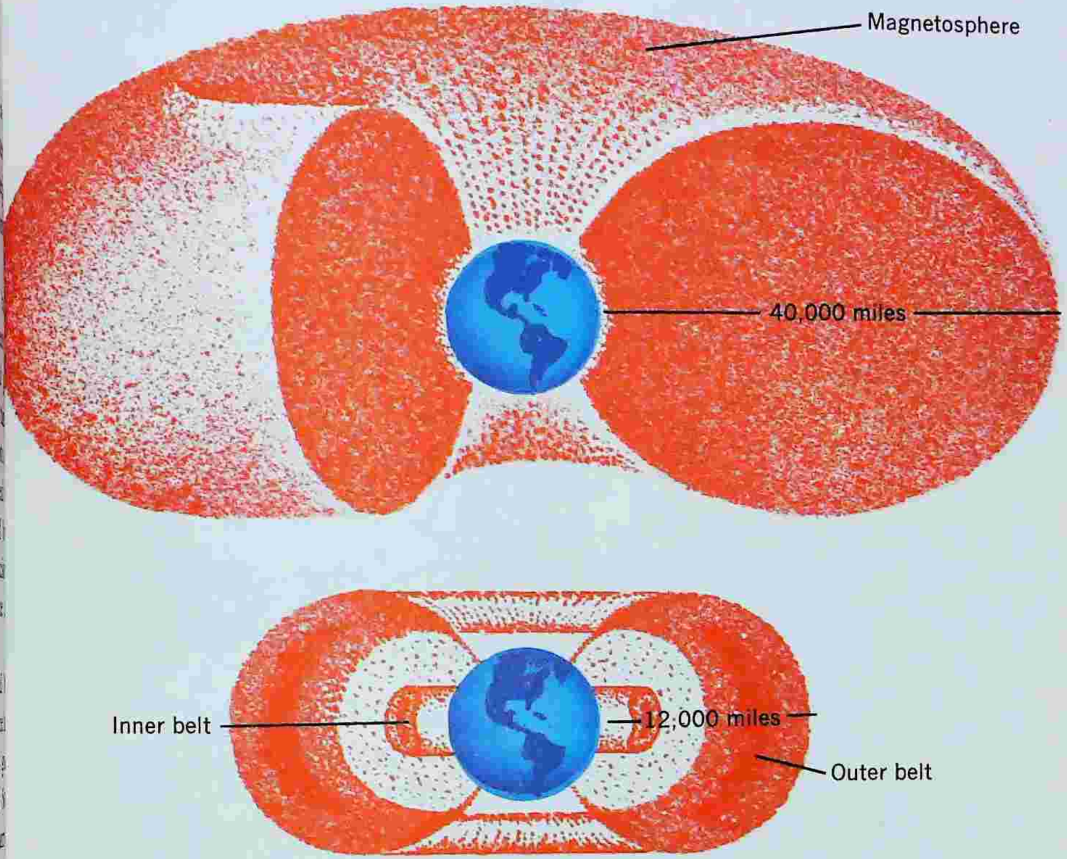
There is no doubt that there is some connection between the violent storms on the sun's surface which produce sun spots and solar flares, and variations in the earth's magnetic field.

Many students of magnetism have been convinced that electric currents in the form of electrically charged particles issue from the sun at all times, whether or not there are sun spots and flares in sight. It has been supposed that these currents, with the lines of force of the earth's magnetic field, exercise an enormous effect upon the space surrounding us.

The International Geophysical Year and the firing of rockets into space have confirmed the correctness of this guess. Rockets fired from the United States and from the Soviet Union, carrying complicated and very sensitive instruments for measuring electrical and magnetic force, have sent back startling news.

From 1958 until 1962, it was thought that the earth was surrounded by two great belts of electrified particles. The inner ring, the smaller of the two, was supposedly several thousand miles from the earth. The larger was many thousands of miles farther out. Each belt was thought to be shaped very much like the

*A United States rocket leaves its launching pad with a great cloud of smoke and flame.*



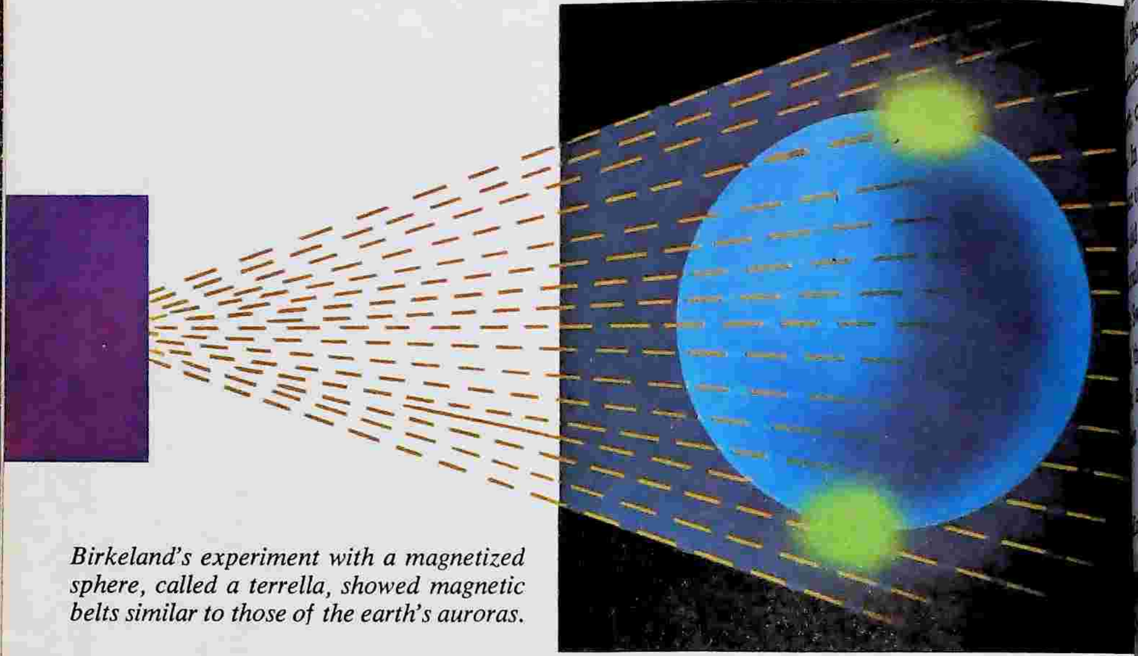
*The top drawing illustrates the latest findings about the Van Allen radiation belt. There is only one belt circling the earth. It extends 40,000 miles from the earth and is called the magnetosphere. The lower drawing illustrates the old theory that there were two bands of radiation that circled the earth.*

shell of a hollowed-out pumpkin with the top and bottom cut off.

In January of 1962, however, it was discovered that the earth is actually surrounded by *one* band of radiation, which extends 40,000 miles from the earth, and is known as the magnetosphere.

Within this extraordinary band, electrified particles, which probably come from the sun, are held in suspension and whirled about by the force of the earth's magnetic field. In other words, the electrified particles are trapped within the ring and kept spiraling from north to south and back again.

The reason that the belt is shaped in this way is that the particles of which it is made have a tendency to twist in spirals about the earth's magnetic lines of force, hurtling out into space from the North



*Birkeland's experiment with a magnetized sphere, called a terrella, showed magnetic belts similar to those of the earth's auroras.*

Magnetic Pole to the South Magnetic Pole.

This great belt, which is in line with the earth's magnetic field, leaves open spaces over the earth at the north and south. It is now thought possible that the electrified particles which leak out of the top and bottom of the ring, enter the upper atmosphere and there collide with air particles. This causes the air particles to glow, and produces the auroras of north and south.

Although this belt of trapped electrified particles surrounding our earth at a distance of many thousands of miles was only recently identified, it was predicted more than fifty years ago. In the same year which saw Roald Amundsen studying magnetism near the North Magnetic Pole, a Norwegian physicist, Kristian Birkeland, began a series of fascinating experiments. He was trying to learn the secret of the aurora. Birkeland used a small magnetized sphere which he called a terrella, or "little earth." Against this he directed a stream of cathode rays which represented the electrified gas particles which stream toward the earth from the sun. He found that when the little earth was magnetized, the rays approaching it seemed to gather in a glowing band above each of the poles.

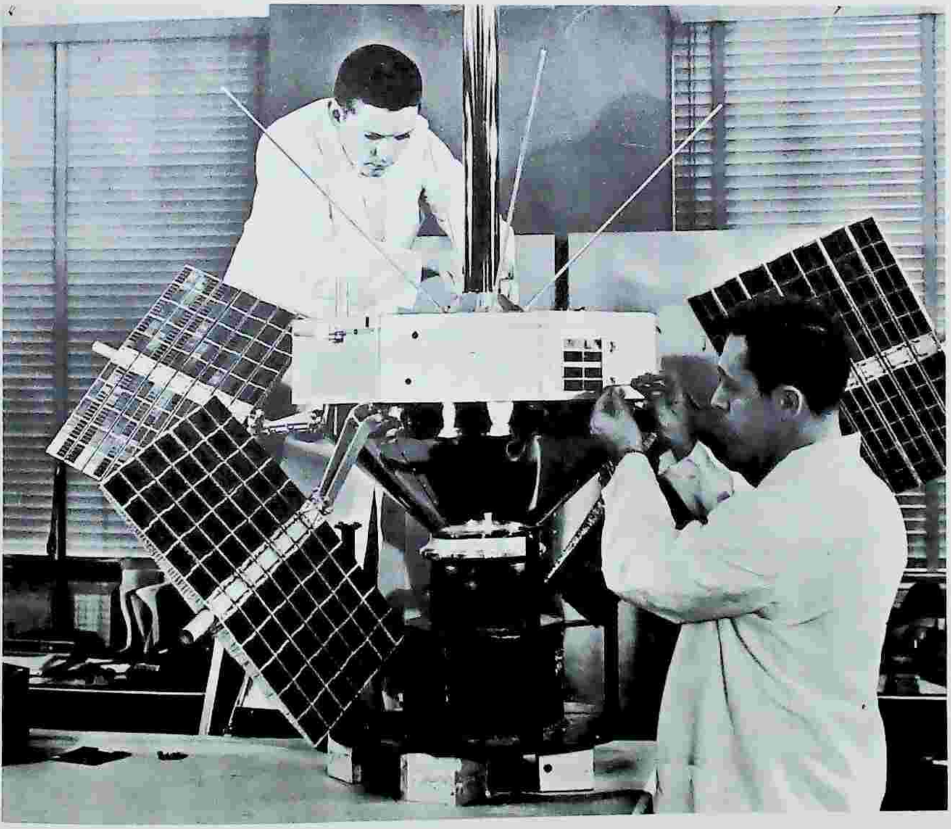
Kristian Birkeland, who was a professor at the University of Oslo, also helped to set up magnetic observatories in the arctic areas and he wrote of the results.

Carl Stormer, who had worked with Birkeland in an attempt to find out the shape of the path along which electrified particles traveled from the sun to the earth, carried the experiments still further. In doing so he predicted the existence of great belts above the earth. Yet he did not show how electrified particles could get into them.

The Swedish scientist H. Alfvén predicted that belts like these would be found, and that they would prove to contain trapped electrified particles.

It remained for Dr. James Van Allen, of the University of Iowa, to announce in March, 1958, that he had discovered the existence of such belts. His discovery was later verified by the flight of the Russian sputnik rocket in August, 1958. These extraordinary areas were known as the Van Allen Belts. In January, 1962, the American satellite Explorer XII, which was launched August 15, 1961 to investigate, among other things, portions of the earth's magnetic field, found there was only one belt.

*The Explorer XII satellite has sent much valuable scientific information back to earth.*

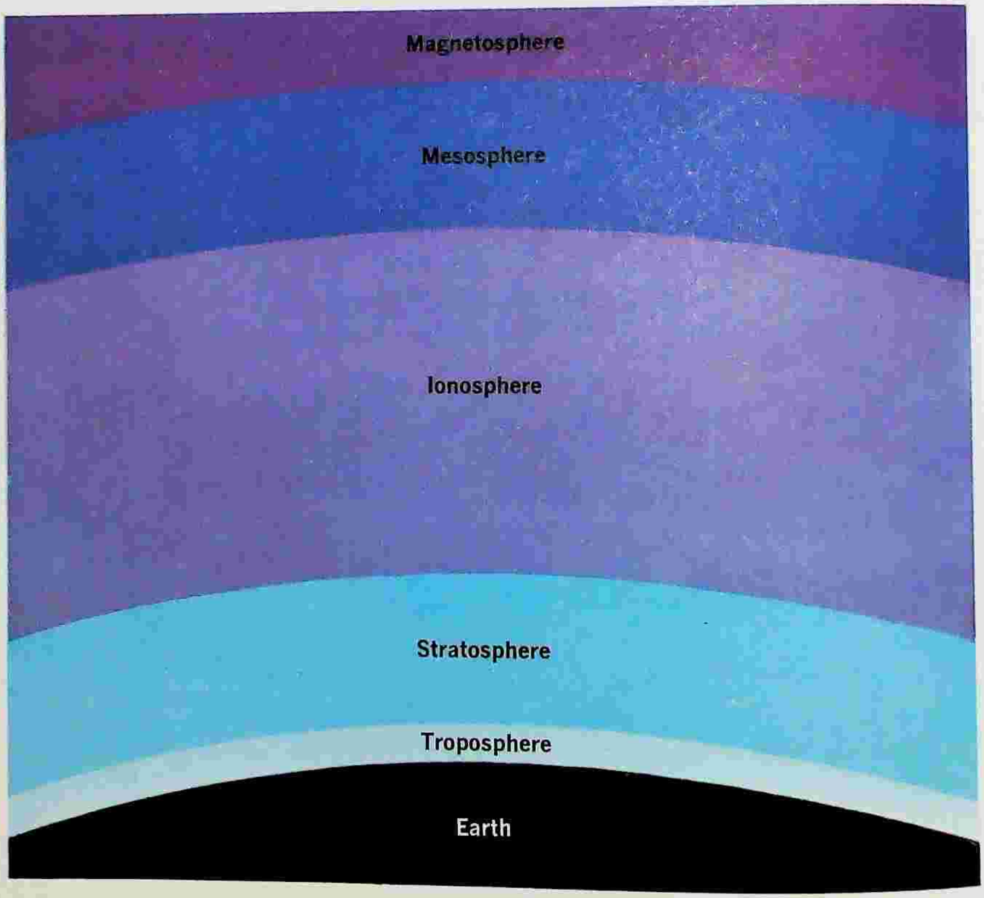


If men are to travel to outer space in rocket missiles they must do so using a polar orbit. Otherwise they would be killed by rays resulting from the bombardment of their spaceships by the furiously active electric particles trapped in the wide band about the center of the earth.

The discovery of the magnetosphere also adds another layer in the earth's environment. The four already known are the troposphere, stratosphere, ionosphere, and mesosphere.

The discovery of the existence of this electrical belt is a great scientific achievement. It does not tell us just what magnetism is nor why it and electricity are closely related. It does, however, give us something to work with, something as important as the discoveries which gave us our first knowledge of electricity and magnetism.

*The troposphere is our zone of weather. The stratosphere is made up of thinner air. In the ionosphere, we see the auroras. The mesosphere is below the newly found magnetosphere. In the magnetosphere, particles become trapped in the earth's magnetic field.*

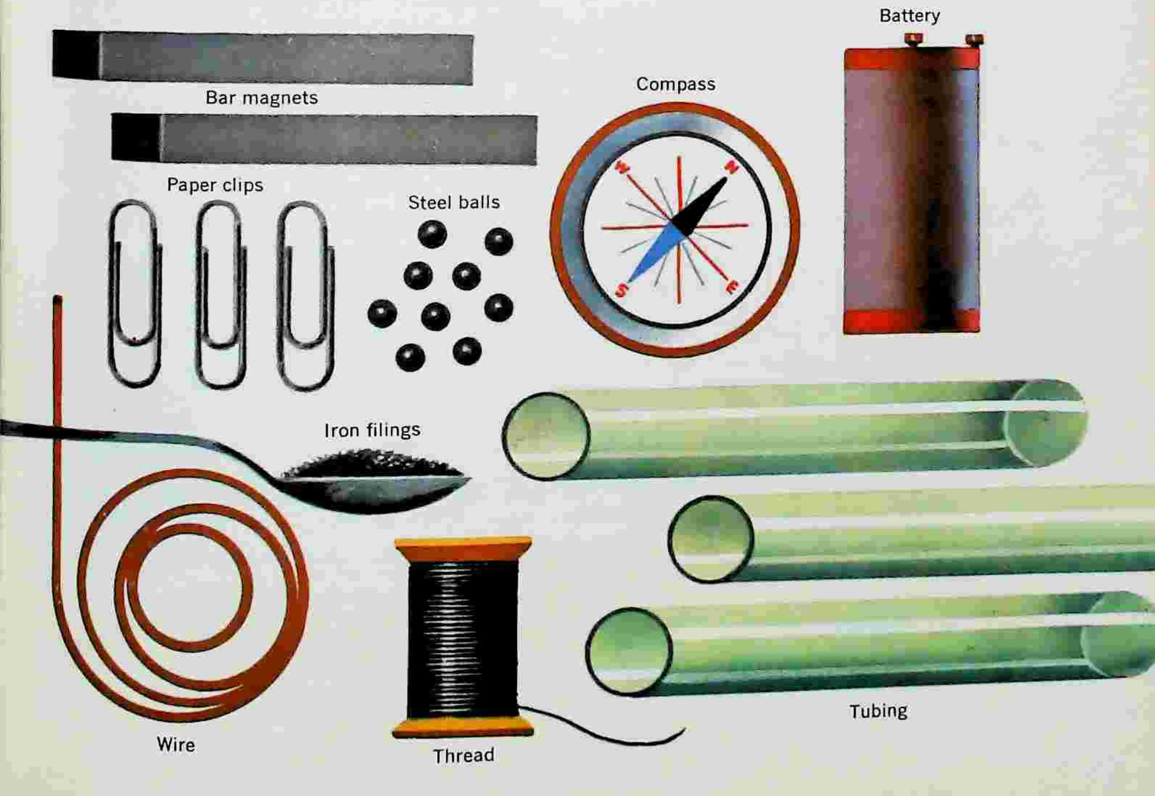


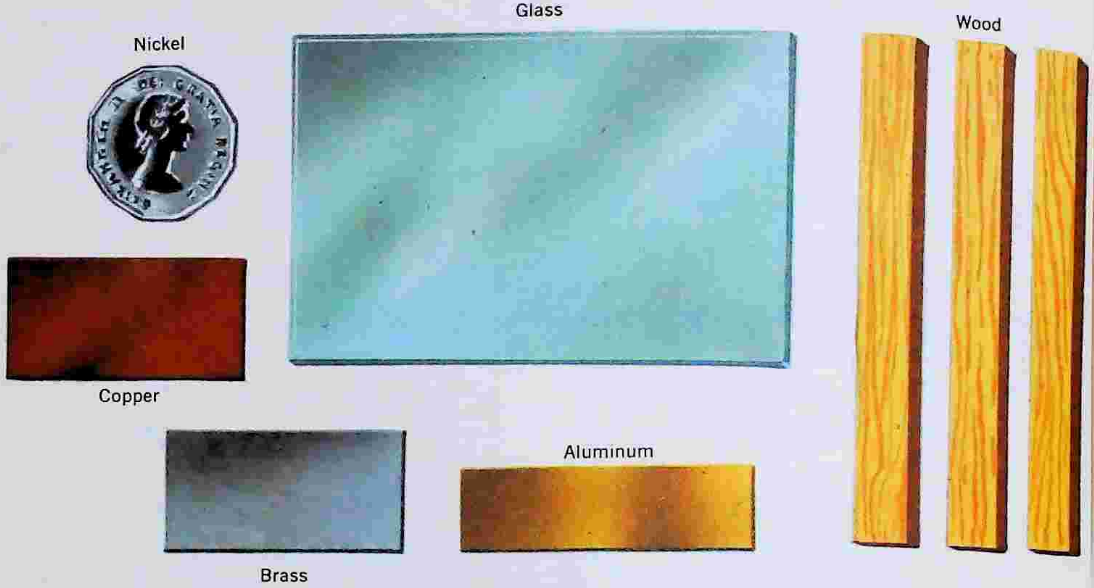
# Experiments With Magnetism

We cannot return to a state of ignorance about the force hidden in that stone from Magnesia which was so mysterious to the Greeks. Even before we start experimenting most of us know many of the answers. Yet the performance of an experiment may be a way to achieve a better understanding of something which we believe we already understand.

There is nothing complicated or expensive about experimenting with magnetism. All that the experimenter needs is the following:

- one or two alnico bar magnets, one or two inches in length
- a compass
- some thread
- ½ dozen or more steel balls the size of BB shot
- a few steel paper clips
- a 2″ or 3″ length of plastic or glass tubing, big enough for the bar magnets to slide through
- a tablespoon of iron filings
- a piece of nickel
- a piece of brass
- a piece of copper
- a piece of aluminum
- 12′ to 15′ of fine insulated wire
- a dry battery, preferably a "hot shot" three-cell battery





a sheet of window glass (or transparent plastic) at least 6″ x 9″

a few thin strips of wood, the thickness of your bar magnet and 7″ or 8″ long.

Note: Complete sets of materials for magnetic experiments may be purchased from scientific supply houses, toy stores, and some bookstores.

### *1. A Magnet and Its Lines of Force*

Place a bar magnet on a table and over it set a sheet of glass or transparent plastic with its edges resting on two strips of wood. If you put the filings in a small salt shaker or vial with a hole or two in the top, and shake it gently over the glass from a height of about half a foot, you will see that the filings arrange themselves in neat and very regular lines curving out from each pole of the magnet and making semicircles above and below the magnet. The ends of these lines are all gathered together at each pole. These curved lines, which without the iron filings to show them off would be invisible, are the lines of force of the magnet. The iron filings are joined together as if they were threads, each individual filing having become a magnet, the north pole of each attaching itself to the south pole of the filing ahead of it. You will notice that at each end of the magnet the filings stand up into the air instead of lying flat. That is because the lines of force at each end of the magnet are both densest and strongest. They are sparsest and weakest between the two poles. If you lift the glass away from the magnet you will see that these standing filings will lie flat.

Suppose the magnet and the sheet of glass were very much larger—as big as the floor of your room—and were still covered by iron filings. You would see, if you ran a small compass along the curve of one of the semicircles, that the compass needle would always line itself up as if it were an iron filing.

It is this behavior of the compass needle, following the curves of the lines of force of that great magnet of the earth, which enables men to navigate ships over thousands of miles of unmarked sea even when the sun and stars are not visible.

### 2. *Attraction and Repulsion*

We have already seen that a magnet cannot be simply said to be something which attracts objects to it.

If you take two alnico bar magnets, each of the same length, and bring their opposite poles close together, end to end, you will find their tendency to jump toward each other so strong that it is difficult to hold them apart.

If, however, you separate them and turn one of them the other way around you will find that they try to get away from each other. It is just as hard to keep them together as it was to keep them apart.

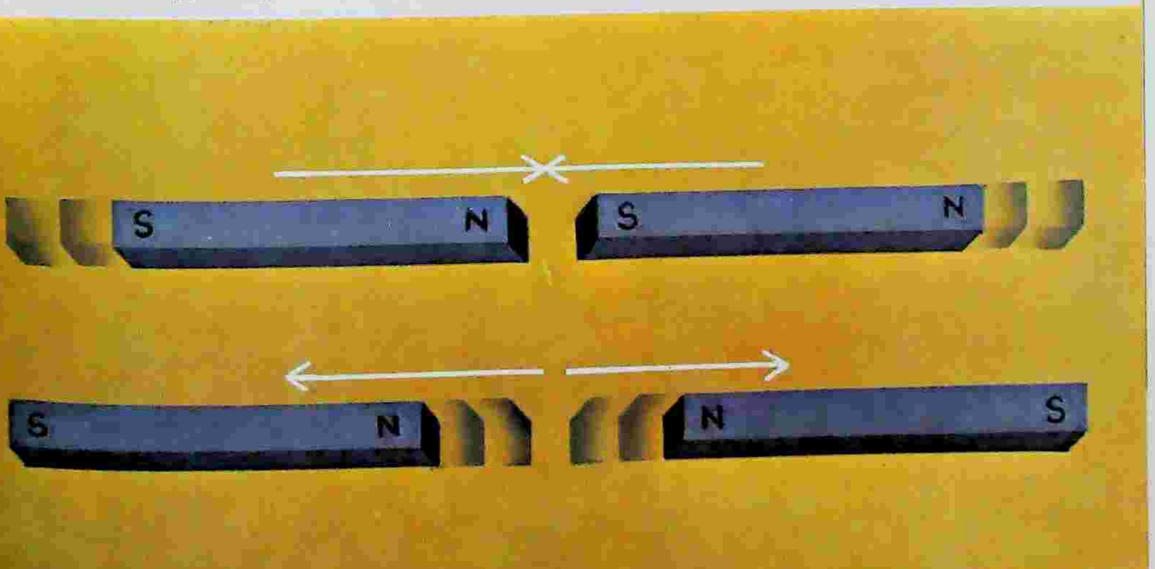
This is because, in the first case, the north pole of one magnet was next to the south pole of the other and opposite poles attract each other. When one of the magnets was reversed, the like poles repelled each other with equal force.

Now if you take the two magnets and join them lengthwise, you will see, if you have brought the north pole of one against the south pole of the other, that they cling to each other to make a single magnet.

### 3. *Magnetic and Non-magnetic*

Put a small piece of copper (such as a copper rivet or a short piece of bare copper wire), a piece of steel (such as a paper clip), a piece of brass, a piece of

*The opposite poles of magnets attract each other; the like poles repel each other.*



*Because steel is magnetic the steel paper clip can be picked up by a magnet.*

nickel (there is not much nickel in an American five-cent piece, but it will do), and a piece of aluminum on a piece of paper and bring a magnet near the paper. You will find that only the paper clip jumps up to attach itself to the magnet. For steel is what we call magnetic, and copper, brass, and aluminum are not noticeably so. The arrangement of the molecules within non-magnetic materials is such that they cannot easily be rearranged so that their north poles all point in the same direction.

The steel paper clip, which is magnetic, but not a magnet by itself, becomes magnetized when it comes within the field of force of a magnet. It is then a magnet so long as it remains within the magnet's field of force.

If you let a paper clip cling to the end of a magnet you will find that it will pick up other paper clips. Take it away from the magnet, however, and you will find that it has lost its magnetic power and will pick up nothing.

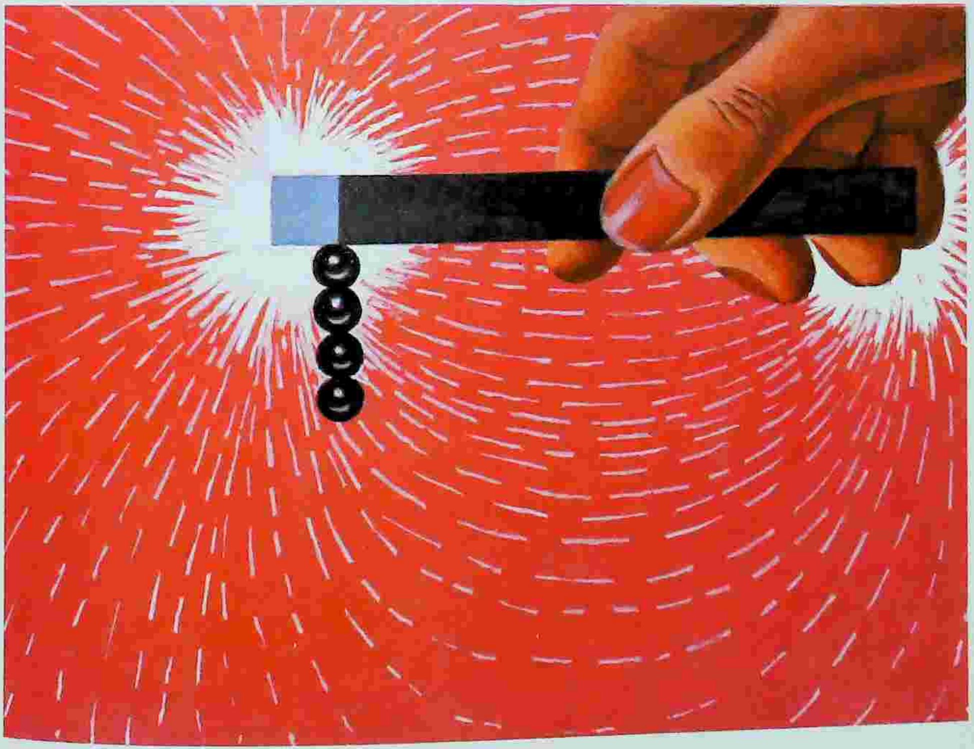
## *4. The Strength of a Magnetic Field*

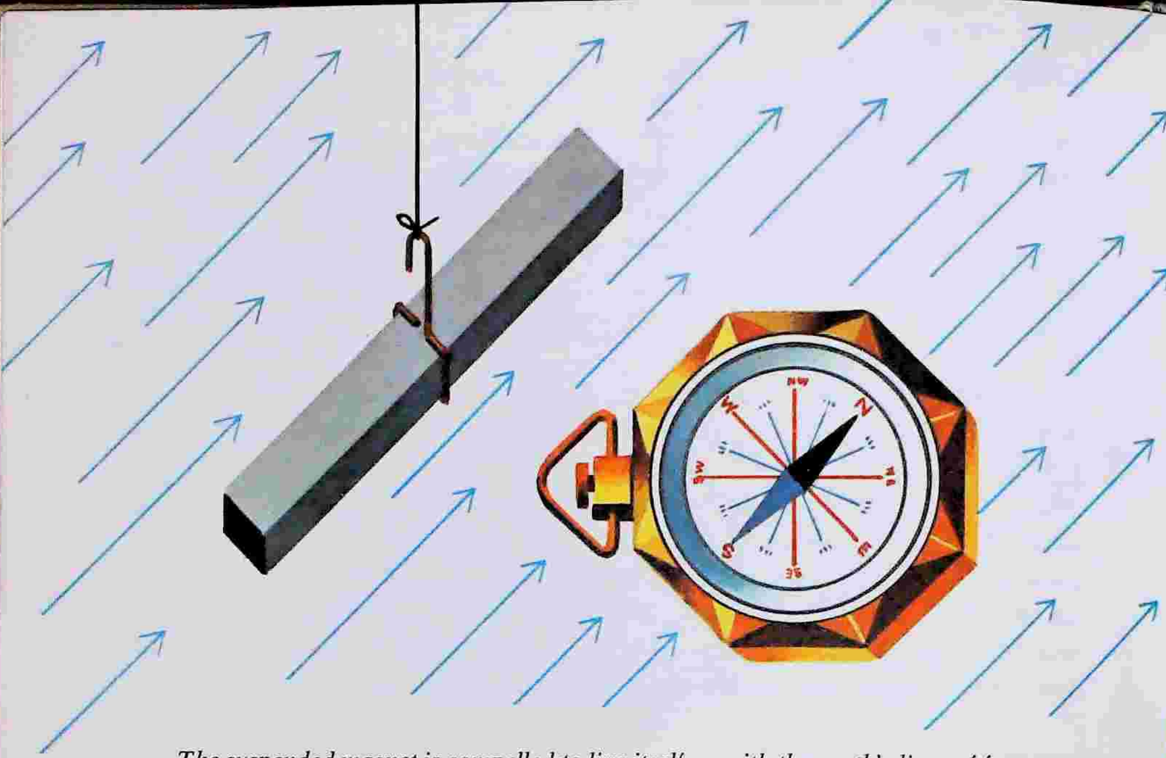
Let a bar magnet pick up a small steel ball such as is used in ball bearings. With this clinging to the tip of the magnet, touch another steel ball. The second steel ball will cling to the first. You will find that you can build up a chain of steel balls, the number depending upon the strength of the magnet and the size of the balls. Each ball becomes magnetized, its molecules lining up with their north and south poles touching. When the length of the chain of balls becomes so great that the outer ball is at the outer limit of the magnet's field of force, the magnetic force will not be sufficient to add any more balls to the chain. In the same way you could see in the first experiment described that the iron filings spread on the glass plate over the bar magnet would only arrange themselves in curved lines or stand on their heads for a certain distance around the magnet. That distance marks the limits of the magnet's field of force.

## 5. *The Compass*

Make a double hook of a piece of copper wire and hang a bar magnet from it so that it makes a kind of handle, as in the illustration. Attach a piece of thread about a foot long to the center of the handle and hang it in some convenient place where it will not be too much disturbed by drafts. Wait until the magnet stops spinning and then no-

*Until the outer limit of the magnet's field of force is reached, the chain of balls grows.*





*The suspended magnet is compelled to line itself up with the earth's lines of force.*

tice the direction in which it is pointing. Without bringing your compass near enough to the magnet to be affected by it, examine the compass and see what it tells you about the direction in which the suspended magnet is pointing.

If the magnet is not too near a radiator or other bulky steel or iron object, it should be pointing in the same direction as the compass needle. In fact your suspended magnet is a compass. It is being affected by the greatest of all magnets, the earth, and is, to the great advantage of sailors and surveyors, compelled by the earth's magnetic force to line itself up with the lines of that force.

You should bear in mind, however, when speaking of north and south, that it is actually the *south* pole of the magnet (or the compass needle) which points in the direction of the earth's North Magnetic Pole, since the north pole of the magnet earth would repel the actual north pole of the compass needle. We call it north because it is a north-seeking pole. Compasses were invented before we understood magnetism.

### 6. *Electricity and Magnetism*

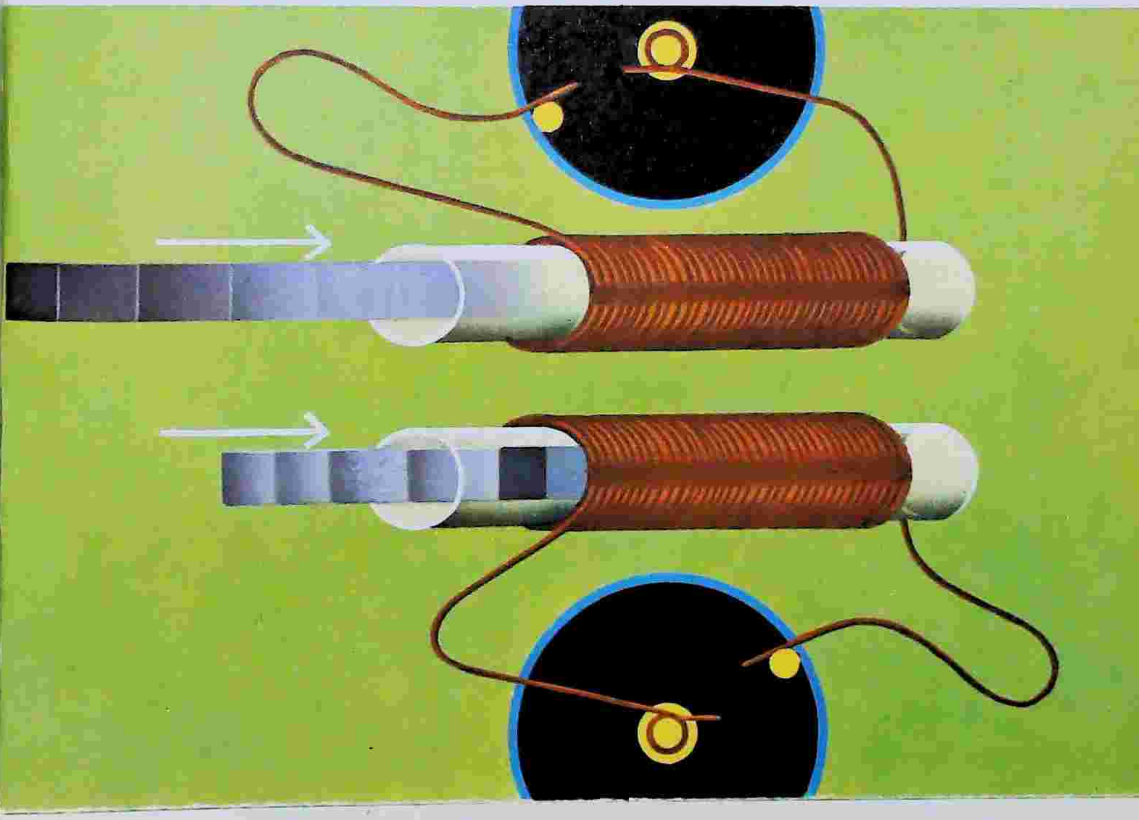
Take a piece of plastic or glass tubing, the inside of which is a little larger than your alnico bar magnet. Wind it tightly with two layers of insulated wire, leaving eight or ten inches of straight wire at each end. The coil of wire may be held firm and kept from unwinding by wrapping it with cellophane tape.

Fasten one loose end of the wire to one of the terminals of your electric battery. Push a bar magnet halfway into the tube and touch the other end of the wire to the other post of your battery. The magnet will either be shot out of the tube or drawn into it, depending on which pole of the magnet is inside the tube. Do not leave both ends of the coil of wire connected to the battery for any length of time. To do so would generate heat in the coil and wear out the battery.

The coil of wire, when a current is passed through it, becomes a magnet with a north and south pole of its own. Such a coil is known as a solenoid. If the north pole of the coil receives the south pole of the magnet, the magnet will be sucked into the tube. If it is the other way around it will be shot out.

You will find also that if a bar of ordinary unmagnetized iron or steel is introduced into the coil and the current turned on, the bar becomes magnetized.

*The coils of wire shown are called solenoids. When a current goes through the solenoid, it becomes a magnet. When the coil's north pole receives the south pole of a magnet, as is illustrated here, the magnet is drawn into the tube.*



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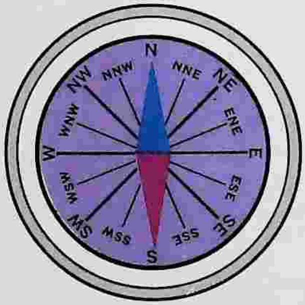

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